SCIENCE IN INDUSTRY

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SCIENCE IN INDUSTRY

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DEDICATED TO

MY MOTHER

CONTENTS

INTRODUCTION

INDUSTRY to-day is not in a very healthy state. True, it provides comparatively good wages for short hours for those employed and enables us to enjoy, at moderate prices, many articles which our grandfathers would have considered incredibly luxurious. But it also provides statesmen with unpleasant headaches, and although economists may provide analgesic balsams, the fact remains that tariffs, quotas, socialism—or any of the other -isms—or attempts to bolster up industry by economic manipulation still leave us unemployment, shortages, and many other problems.

This is not in any sense a political argument. In these days of heated controversy I think it is sometimes a relief to deal with things like oxygen and hydrogen whose behaviour under given circumstances can be predicted with some certainty. Chemists can spend their week-ends in peace without fearing that some of the carefully stoppered bottles on their laboratory shelves are going to take the opportunity to go on strike, make a 'gesture', or assert their independence. I hope that this book may suggest that a remedy for most of our troubles in industry is less politics and more science. When we consider the sums spent by governments upon scientific research in industry—and all the governments of the world are in the same boat in this respect—compared with the amount spent on inspections, tax collection, and all the other paraphernalia of control, some might be tempted to think that science was relatively unimportant. It is perhaps significant that there are more company directors, sailors, soldiers, accountants, doctors, and lawyers in Parliament than there are scientists. I do not suggest that more scientists in Parliament would help us at present, for the atmosphere of the political platform is not always conducive to the search for pure truth. But I do suggest that much more regard for science in industry on the part of our politicians would solve many vital problems.

Science can exist without industry—it did so for hundreds of years. But industry cannot exist for five minutes without science. Invention and research are the very life-blood of the industry that makes possible a civilized nation and, one might add, the collection of millions of pounds in taxes. This only too often is the attitude of the statesman. You may remember the story of Faraday's demonstration of his first primitive dynamo to, I think, Gladstone.

'Tell me, Mr. Faraday,' said the politician at last, 'what use is this apparatus?' 'Sir,' replied Faraday, 'I do not doubt that later you will be able to tax it.'

The damaging effects of a lack of scientific knowledge in dealing with the regulation of industry is illustrated by motor taxation. The government took upon itself to define horse-power in an internal-combustion engine and then proceeded to tax it. The reply of the motor manufacturer was to produce engines which made the horse-power definition look foolish, but the combined effect of taxation on both the internal measurements of the engine and on petrol has been to produce particular types of cars which, although marvels of efficiency and economy, are not the cars that would have normally evolved if there had been no artificial influences of restraint.

We elect our representatives and we have only ourselves to blame if we elect men who lack the scientific spirit and outlook. Perhaps we are satisfied because we lack it ourselves. I hope that this book may show that we cannot afford to avoid it; that without science we should be, literally, back in the jungle. Although many people protest that they long for a primitive life, I fancy that they would soon be howling for the comforts of civilization—that is if they had survived the eccentricities of Nature's air-conditioning, the stings of insects, and the inconvenience of having to catch their meals before they could eat them.

It has been possible in a book of this size to cover only some aspects of industry. But it is interesting to note that industry is itself simply the repetition many times of scientific 'experiments'. The silk factory is distinguished from the lone chemist making a yard of rayon in his laboratory more by the amount of material produced than by the methods used. Science, it should be noted, not only produces the basis of industry—the manufacturing processes—but also provides for their repetition on a grand scale. In many industries the marvel is not so much the fineness or quality of the products as the speed and cheapness with which they can be made by the use of scientifically designed machinery.

There is no branch of science of which use is not made in industry, from mechanics and chemistry to geology and even archaeology. The engineer designs and builds the machinery for thousands of manufacturing processes. He takes the chemist's reaction performed in a test-tube and devises methods of doing it in containers

as big as a house. The geologist shows where the raw materials of industry are to be obtained, the biologist plays an increasingly important part in a hundred industries concerned with living things, while even dealers in the antique cannot live without the aid of science.

War has shown that the scientist is no longer a rather vague individual with a book of notes which nobody else can understand and his head in the clouds. He is a man concerned with realities. It is important to grasp that the so-called 'academic scientist', pursuing knowledge simply for the sake of knowledge, may be founding the industry of to-morrow. Faraday's academic calculations led to the vast expansion of the electrical industry. Hertz and his academic investigation of the ether led us direct to broadcasting. Nearly every great industry of the last hundred years has been founded on 'pure' science; by following the workings of different industries we shall unfailingly encounter every great law or principle of science.

The war which ended in 1945 held up the production of 'consumer goods' of every kind so that for some years we are not likely to have a 'world of plenty'. But the intense research carried out for military purposes resulted in advances being made in six years that might normally have taken three or four times as long. To-day we have the knowledge necessary to manufacture more things conducive to the health, wealth, and comfort of mankind than ever before in the history of the world. Whether they also contribute to the happiness of mankind is for us to decide. Such great feats as the fabrication of the 'Mulberry Harbours', 'Pluto', and the mass production of complex machines such as the four-engined bomber show that, from a scientific and engineering point of view, nothing is now really impossible. It is not necessary to have faith to move mountains; modern machinery and explosives will do it for us if we feel that it is necessary.

This book will show how science enters into every phase of every industry and how, whether we like it or not, we are dependent upon science during every minute of every day. To talk of 'abolishing' science, or even of controlling it, is ridiculous. You cannot abolish or control a method of thought. What we can and must do is to control the manner in which scientific discoveries are used. The war has shown the ordinary man only too clearly that the scientific discoveries which make possible the £100 car also make possible

the mass production of tanks and bombers. We must control not merely to avoid self-destruction on an even greater scale than during 1939–45, but for the more positive reason that only by directing industry and distributing its products wisely can we rid man of much of the drudgery, unhappiness, and fear which still pursue him. And control can only safely come from the people themselves. Before we can control, we must understand. This book may serve as a simple introduction to understanding better how industry is based upon scientific discovery.

CHAPTER I

MASS PRODUCTION

ALL industry is built upon science. Without science the manufacture of the millions of articles which we now regard as everyday necessaries would revert to the rule-of-thumb methods of the home workshop. A motor-car, if it could be built at all, would take years of work to produce, and then, because it had been produced by one or two men working independently, its repair would necessitate the individual construction of new parts 'made to measure'. If a new sparking-plug were needed it would have to be specially made, for each of the individual craftsmen would, no doubt, have his own idea of the best size for the screw.

This was, slightly less exaggerated, the actual position in the earliest days of motor-cars. Each model was experimental. There was no question of walking into any one of a thousand garages and being certain that you could purchase spare parts for your car at a few minutes' or hours' notice. To-day you can be reasonably sure that if a car suffers even major damage new parts can be ready, whether small or large, within a few hours, and, equally important, that these parts will be exactly like those destroyed, with no manipulation necessary to make certain of their fit.

What has brought about this great change? It can be summarized in the phrase 'mass production'. The term is much misused. It does not simply imply making things in mass. It is not the number of articles produced, but the method of the production that constitutes mass production, although in the nature of things such plans cannot be applied to articles for which there is not a large market. Production on a large scale in factories originated a century and a half ago, but mass production is essentially a twentieth-century development. Its first great application was to the motor industry, but it has been extended in many directions to embrace all those articles which are consumed in millions.

What is mass production? How does it differ from the factory methods of the early nineteenth century? The Industrial Revolution was really based on the replacement of human power by steam power. Instead of human hands moving a shuttle across a loom, power machines were devised which did this action very much more rapidly. Instead of a man laboriously cutting a piece of wood

with a hand saw, he used a circular saw driven by power. These are merely two simple examples of thousands of changes that occurred. For convenience, industry moved from the home to buildings specially erected—factories. You could not use machinery in the home, but there was no other real reason for building factories.

At the same time there was a certain amount of standardization —men began to make things the same size for the obvious reason that machines could not so easily deal with all sorts of odd sizes. A cobbler making a pair of shoes would measure the foot of his customer and cut the leather accordingly. The machine alone could not measure the foot, so manufacturers adopted the next best principle: they devised machines to make shoes in a number of different sizes into one of which ninety-nine feet out of a hundred would fit comfortably. This was large-scale production, and it enabled the ordinary man to enjoy a great many necessaries which previously had been luxuries, but it was not mass production.

Mass production is really the application of scientific methods to factories. It involves many things, but first of all the invention or design of an article or series of articles which will be almost universally in demand Methods are then devised for manufacture of the articles with the minimum waste of time and material; these methods depend upon the utilization of all waste products, and the planning of the process of manufacture in such a way that there is no waste of movement or power.

The ordinary factory method of making a machine was for different people to make different parts according to blue prints. They would then meet and fit the parts together. In mass production the parts literally flow together, each operator having a single task to perform as the work passes before him, by the aid of tools which permit the minimum possibility of human error. In a mass-production factory you will not see workmen rushing about; the work is brought to them at a convenient speed, and as soon as they have finished a task on a particular article, it passes on. In many cases the 'job' continues to move slowly all the time it is undergoing treatment.

Perhaps it will be easier to understand what happens in mass production if we take one industry, a pioneer in this field. A modern motor-car begins as masses of steel, cast iron, and other metals. These raw materials enter the factory at one end and

proceed without a stop to be turned into motor-cars, the cars emerging at the other end of the factory ready to be driven away. The main artery of the factory is the 'assembly line' on which the cars are gradually built up. It is probably a conveyer which passes between a great number of men, each of whom works on the growing car. The first men, for example, may perhaps bolt or weld together the parts forming the chassis, then other men will add the body, others will put the engine in place, others will add the electric equipment, until finally the car is having its tyres fitted and is 'launched' on to the floor, able to move for the first time under its own power.

In this very short description several thousand actions have been compressed. The growing car passes not only before operators, but through tunnels in which the paint is dried and so on. And this is only the main artery. Branching off are a number of other lines on which parts are built up. For instance, to assemble the engine on the car would mean holding up the chassis for a considerable time. What happens is that while the chassis is being put together, men on a 'branch' line are assembling the engine. The hundreds of parts are mechanically fed to them as they are required, and the engine seems to be not so much built as growing under their hands, so that at the moment when the chassis is ready to receive it the engine is complete, tested and waiting to be put in position and bolted down.

There are branch lines not only for the engine but for many different parts such as the springs, which will be made and prepared on another line. In the early days of motor manufacture by ordinary factory methods a leaf-spring would be made by one man, who would take the pieces of iron, bolt them together, bend them for erection, and carry out every stage of construction until at last one leaf-spring of the type required was ready. Very different is the method by mass production. The spring is built on a conveyer in exactly the same way as the chassis. One man controls the machine which bends the first piece of steel, and it passes to another who sends it through a furnace where it is heated as required; another operator inspects it, another puts in the bolt, another puts on the nut, yet another smooths off the rough pieces, and so the work proceeds until the spring is complete. Actually up to fifteen or twenty men may be employed, each upon a different task, as the spring passes on the conveyer in front of them.

In the intervals between workmen the article being manufactured may be subjected to various treatments automatically. For instance, the spring we have been discussing will probably at different points be carried by the conveyer through a furnace, an oil-bath, a nitrating bath, and a drying-bath. It is in keeping with the principles of mass production that the surplus heat from the furnace used to heat the spring at an early stage will later be used to dry the paint during one of the last processes.

Another feature of mass production is that the workman is given few chances of making an error. For instance, in the spring where it is necessary to make a hole to take the bolt, instead of laborious measurements to discover exactly the right position, the operator will have a press with 'stops' which will hold the bar in place. The use of such a press is only possible where thousands and even millions of bars with holes in exactly the same location are required. The temperature of the furnace and of the oil-bath is regulated automatically so that the operator does not have to trouble with measurements. Some of these devices are exceedingly ingenious. In cutting gear-wheels the cutting-machine will stop itself when exactly the required depth has been reached.

This emphasizes another aspect of mass production—its accuracy. People often talk disparagingly of mass-produced articles as if there were something inferior about them. In practice, because they are produced under ideal conditions by the finest machinery possible, they are often far more accurate than the hand-made article, and, provided the material is equally good, there is no reason why they should be in any way inferior. If the 'stop' on a press, for instance, is placed with an accuracy of one ten-thousandth of an inch, every hole bored with its aid will be accurate to the same degree. If these holes were made as the result of individual measurements on a bar, each one would vary, perhaps very slightly, but nevertheless they would differ. Adjustments could be made when assembling, but the possibility of interchanging any part of one motor-car with the similar part of another would be less even if the individual case was perfected at a cost out of all proportion to the value of the work.

Mass production involves the use of very accurate measuring instruments. It is common to work to an accuracy of one ten-thousandth of an inch, involving the use of checking instruments accurate to one hundred-thousandth of an inch, and to make

these instruments, master gauges may be necessary which are accurate to a millionth of an inch. Measurement has reached its highest point as a result of the demands of mass production for accuracy.

The motor-car represents one of the most complicated forms of production, for a motor-car is itself an assembly of a large number of articles that have been individually mass-produced. Each part of the motor-car—the dynamo, the gauges, the distributor, the horn—all may be mass-produced under the same principles. The number of articles required is so great that many manufacturers find it convenient to produce them in different factories, arranging a flow of them, either by conveyer or wheeled transport, to the main assembly factory. But the methods employed remain exactly the same.

In some other industries the actions required are not nearly so numerous or involved. Mass production of cigarettes has been brought about by the invention of automatic machines able to perform the work of a number of operators without human intervention or, put in another way, able to do the work of a hundred girls in the same time.

The automatic cigarette-making machine, while complicated in appearance and exceedingly ingenious, is fairly simple in principle. Instead of individual cigarette papers, a long roll of cigarette paper of the appropriate width is used, and the first step is to print on the paper the name of the brand. This is done by a machine which works at a regulated rate, so that it makes an impression so many times a second according to the speed the 'tape' of paper passes under its stamp. The paper then has the tobacco, cut very fine, placed on it from a funnel. It passes farther along, and one edge is folded over the other, the opposite edge having been gummed by another device. At this stage the cigarette is like a long tube of tobacco, and the final stage in manufacture is the cutting into the required length. This is done by a sharp knife which descends at regular intervals. It will readily be seen that in this machine everything is done by timing.

The apparatus does not measure the required lengths of cigarettes, but is so constructed that, with the paper being fed at any speed, the other movements take place at desired intervals, so that every cigarette has the name printed in exactly the right spot and is cut to exactly the right length. This timing is achieved, not by any

clocking device, but by arranging for mechanical intervals. A cam can be made so that it actuates a piece of mechanism at any interval during a revolution, and there are other 'delaying' devices, with gears enabling engineers to make any required relationship exist between the speed of movement of one wheel and another. It would be simple to have a human operator making a knife descend at the required intervals, but it would not be so cheap, accurate, or fast as making this action depend upon the speed at which the paper was being fed into the machine. No human operator could make a knife descend at accurate intervals 50,000 times an hour, but this speed is now achieved by cigarette-making machines.

All through industry we find these automatic machines. Their principles are the same whether they are making cigarettes, wrapping sweets, sealing tins of food, or cutting gear-wheels for motor-cars. It will be noted that, originally conceived to save time, the automatic machine can divert human labour to directions in which intelligence is essential. Machines mean cleanliness. They can be applied to work where contact with human hands is dangerous to user and operator alike. They are not the enemy but the friend of mankind. A road might be built with its concrete mixed by a thousand men each using a small spoon, but machinery will do far better by abolishing the sordid tasks to which modern labour can rise superior.

This, broadly, is the outline of the main principles of mass production. What are its objects and achievements? Its object, of course, is to reduce the cost of manufacture, not only with the idea of making bigger profits but to enable a greater number of people to afford the article and therefore to stimulate the demand. Mass production, in a sense, makes its own market. As long as cars cost £1,000 each, the number of potential customers was very limited. When they can be manufactured for less than £100, the number of customers begins to be limited only by the population of the world. The huge increase in the number of cigarettes smoked is due not only to a change in social customs but to the fact that good cigarettes can now be produced in numbers which would be impossible if we were restricted to hand-labour. There would not be sufficient girls in the country to make the cigarettes if there were no machines for this purpose.

At the present moment the number of potential buyers of television sets is limited because of their cost. If the price were

halved or reduced still further there would be many more buyers. There are certain technical difficulties in the application of entirely mass-production methods to television receivers, but undoubtedly in time mass-production methods will bring the price of sets down to a point where they become necessities for the home instead of luxuries. It has been estimated that an increase in production units of 500 per cent. results in a reduction in costs per unit of 50 per cent. In other words, make five times as many articles by mass-production methods and you can afford to sell each article at half its former price. A single motor-car might cost up to £10,000, perhaps more, to produce. But we could produce a million of them for £100 each.

Another startling effect of mass production is the lowering of the standard of skill required by the workers. Perhaps this is hardly a fair way of putting it, but what actually happens is that a number of scientists do the highly technical work once and for all. Others, not so highly trained, are able to repeat it again and again. To make a single car requires the knowledge, training, and experience of perhaps fifty experts of different kinds—electrical engineers, fuel specialists, acoustical engineers, and biologists. If those fifty men had to give their services to each car, the price of the finished article would make it prohibitive except for millionaires. But by devising machines and methods to put their knowledge into action, any ordinary man can have the benefit of their brains for a few pounds.

The effect of mass production most commonly noted is, of course, standardization. As many pieces as possible are made the same size—the bolts that hold the engine in place, perhaps, are exactly the same as those that hold the springs. This is an obvious economy. There is the further advantage that replacement of worn parts becomes exceedingly simple, for the new parts will have been made in exactly the same way as the old, and they must fit easily because they are virtually identical. A new engine can be put into a car with far less work than may be required to repair an old motor. There are many people who object to standardization for various theoretical reasons, but common sense—and much science is simply organized common sense—suggests that when you have found the ideal size and shape for something it is better to use them than to effect a multitude of unnecessary changes. 'Ideal' has a purely temporary significance. To-day's ideal car

gives place to next year's improved model, and mass-production machinery is altered accordingly.

Most of the objections raised against quantity-produced articles are based upon the entirely mistaken idea that something which is produced by the thousand must always be inferior. The contrary is often true. While hand-made cups, for example, may have some individual quality which makes them valued, they cannot be so perfect in shape as those made by the hundred, since each of these is an exact replica of the original. If the original pattern is wrong, all are wrong, and this alone affords some guarantee of quality when the high cost of the necessary plant is considered. Manufacturers conduct tests before production instead of achieving their results at the expense of the purchaser.

From a purely artistic point of view, the hand-made article has certain claims, but these advantages are becoming fewer every year as manufacturers appreciate that, for many purposes, appeal to the eye is not less important than the appeal to common sense and utility. The hand-made article was, and must remain, for the few. The comparatively high standard of comfort and the vast number of possessions we now enjoy would be impossible without mass production. Whereas in the days of 'homespun' a woman would have to make a dress last a lifetime, to-day she will buy several dresses a year. It is often said that the advantage of the hand-made article was that it 'lasted'. This was often a necessity, thrust upon a dissatisfied or prejudiced public who had no method of securing improvements which time had shown to be eminently desirable.

CHAPTER II

SCIENCE KEEPS OUR FOOD

THE entry of science into the business of feeding the people of the world can result in the threat of genuine starvation being removed once and for all. In normal times it is a little difficult for us, accustomed to finding every greengrocer, butcher, and fishmonger carrying a stock more than sufficient for our needs, to visualize the days when hunger was never very far from any country. The failure of a corn crop, a plague amongst cattle, or some other disaster, led almost inevitably to famine. It is only with the last century that this terror has been largely removed by the discovery of scientific methods of storage. These methods fall largely into three classes—refrigeration, dehydration, and canning.

Before the invention of artificial refrigeration, methods of storing food were exceedingly limited. Meat could be salted or smoked and dried, vegetable products to a very limited extent could also be dried; but on the whole, food was a considerable problem during the winter, and nations very rarely had any great reserve for emergencies.

Early refrigeration was primitive and made use of natural ice. Generally, the object was to preserve the ice for use as a luxury in the hot weather rather than for the ice to preserve food. The ice was cut from frozen lakes in winter, the blocks being stored in pits lined with straw or other insulating material and covered with earth. This insulation was sufficient to prevent the heat of the sun penetrating to the ice, and the pit could be opened in midsummer for the ice to be removed.

This method of ice storage was used by the Romans, and even during the last century there was considerable export of ice from Norway, Canada, and other countries where the lakes froze during winter. Artificial ice was not known outside the laboratory. 'Freezing mixtures' were used to produce ice-cream, the commonest being a mixture of crushed ice and salt, all of them calling for ready-made ice.

Even after the invention of machinery for the artificial manufacture of ice, the importation of ice to Britain from Norway continued, for artificial ice was expensive. Ships equipped with special insulated wells were used, and continued to call at London until the beginning of the 1914–18 War.

The discovery that ice, or perhaps we should say cold, could be produced artificially had tremendous results. The discovery was, of course, made in the laboratory. Scientists for a considerable time had experimented with the production of cold, chiefly with the object of liquefying gases. It is unnecessary to deal with their experiments in detail, but they made use of two principles the fact that a gas becomes liquid at a higher temperature than normal if its pressure is greatly increased, and that when there is rapid evaporation there is a fall in temperature. It is these principles that are used in commercial refrigeration. If you do not already appreciate the fact that rapid evaporation produces a lower temperature, simply lick the back of your hand and blow upon its surface. The current of air causes the moisture to evaporate and the cooling effect is felt immediately.

The facts about pressure are perhaps not so widely understood. An increase in pressure raises the temperature at which a gas becomes liquid, but there is a point, as the early experimenters found, above which no amount of pressure will produce a liquid. This is called 'the critical temperature'. When the change from liquid to gaseous form, or vice versa, takes place, there is also absorbed or released a certain amount of heat—'latent heat'—which is quite independent of a rise or fall in temperature. The commercial refrigerator takes advantage of the heat which is absorbed when a liquid is converted into a gas. The heat has to come from something, obviously the surrounding material. This may be the wall of a refrigerating chamber or a tank of brine. The extraction of this heat reduces the temperature and produces 'refrigeration'. Compressing the air in a bicycle pump produces heat; expansion would produce cold.

The ordinary domestic refrigerator works in one of several different ways. In the electric refrigerator a small motor works a pump which compresses the gas, usually sulphur dioxide because of its convenient critical temperature. Under ordinary pressure this gas becomes liquid at 18 degrees below freezing-point. The compressor, by raising the pressure, makes the gas turn to liquid at a higher temperature. It then passes to an evaporating chamber and, in the process of turning from liquid to gas again, absorbs heat from its surroundings, producing refrigeration.

For domestic purposes a temperature below freezing-point is only occasionally required; for example in the production of ice

cubes or ice-cream, and the refrigerator is therefore set for a temperature rather above freezing-point, but sufficiently cool to preserve foodstuffs for a considerable time. The temperature is regulated by a thermostat which switches on the refrigerating mechanism when the temperature reaches, say, 40 degrees, and switches it off again as soon as it falls to 35 degrees. The walls of the refrigerator are well insulated so that the 'cold' escapes slowly, and the intermittent working of the apparatus effects a great saving of gas or electricity, although the cost of power, even for continuous working, is very small.

There are many types of domestic refrigerator, worked by a variety of sources of energy from gas to oil. Where heat is used, as in the gas refrigerator, it is applied to the evaporation stage of the refrigerating cycle, but where mechanical power is used, as with electricity, it is applied to the compression stage.

In the big industrial refrigerator, producing cold on a large scale either in storehouses or in ships carrying meat, the sulphur dioxide or ammonia is first compressed by a mechanical pump, and then cooled by passing through metal coils so that it becomes liquid. It then passes to an evaporator surrounded by brine, a solution of salt in water. When it evaporates heat is absorbed, and this must come from the brine, causing it to drop in temperature. Brine is used because its freezing-point is considerably below that of pure water. A pump circulates the brine through the whole of the refrigerating chambers, keeping them at the desired temperature, and then returning it to be cooled again. The brine may simply pass through pipes, or into apparatus corresponding to a radiator, with the difference that as it is filled with cool liquid it absorbs, instead of releasing, heat from the air. The gas, meanwhile, passes back to the compressor to be converted into liquid once more, and so the cycle continues.

As described, it may sound as if these actions take place successively. Actually the process is continuous—some of the gas is being turned to liquid all the time, while some of the liquid is being evaporated. The whole apparatus can be sealed, so that there is no leakage of gas, and it will continue working for years, with only the usual maintenance of moving parts.

These installations on ships have revolutionized the food industry. Butter from Australia can be carried for weeks through temperatures varying from 50 to over 100 degrees Fahrenheit. The

temperature inside the refrigerated holds remains the same—low enough to prevent the bacteria that cause decay becoming active. The cargo when landed in England is as fresh as on the day it was packed, and while some people profess to be able to detect the difference between 'chilled' and 'fresh' foods, the fact is that Britain's huge population is mainly dependent on the constant coming and going of refrigerated ships. There are certain cases where freezing may produce vitamin deficiency, but careful research has shown how most of these difficulties may be avoided by keeping each particular type of foodstuff at its own most suitable temperature. Eggs, butter, meat, fruit—all have been found to have a particular temperature at which they may best be preserved without serious loss of flavour or nutriment.

During the last twenty years there has been a phase of 'self-sufficiency' amongst nations for reasons that are far from scientific in the proper sense of the word. This was accentuated by the war, which interrupted normal imports. From the technical point of view it is, of course, madness to say that it is better to be half-starved on food grown in your own industrial country than to exchange manufactured products for foodstuffs produced in specializing countries. The vast increase in the population of the world during the last century could not have taken place without the free exchange of foodstuffs for manufactured goods. The great wheat-fields of Canada, the United States, and Australia, and the vast ranches of South America supply food for the industrial workers who, in return, send out manufactured products which it is not worth while to make in small quantities on the spot. In this carrying of foodstuffs thousands of miles, refrigeration—originally discovered as the result of experiments to see what happened to a gas when it was compressed—plays a vital part.

The production of ice itself is still an important industry. Quite apart from the large amount required for cooling drinks in hotels, now generally produced in their own local refrigerators, huge quantities are required for shipping on to fishing vessels. The largest ice-making plant in Britain produces 220,000 tons of ice every year for this purpose alone. The method of producing the ice is the same as that described for refrigerators, the cooled brine being used for freezing water in large moulds. Ice-blocks are released by bringing the moulds into momentary contact with hot water; and they are then loaded automatically to a conveyer, which

takes the ice direct to the ship at a nearby quay so that it is not touched by hand at any moment of its manufacture.

The same system is used for the increasingly popular ice-rinks. In this case, the brine is circulated below the water, freezing it into a hard floor. A constant flow of cooled brine keeps the temperature under the ice well below freezing-point, and when the ice is badly marked it can be refrozen with new water.

Ordinary methods of freezing foods are limited in application. They are not suitable for all foods and will keep some substances for only a certain period. In the ordinary way, when a vegetable such as a bean is frozen, it is spoiled. It becomes black, tough, and uneatable when unfrozen. The reason for this is that, during freezing, crystals of ice form inside the millions of cells that make up the vegetable. These crystals are sharp and penetrate the cell-walls. As long as the vegetable remains frozen no particular effect is noticed, but as soon as it is thawed for eating the liquid is released through cuts in the cell-walls and the food becomes distasteful.

For many years scientists experimented with a method that would freeze foods without forming sharp ice-crystals. They realized that the perfection of such a method would enable many kinds of food which could not be preserved by ordinary refrigeration to be kept indefinitely. The secret was realized to be 'quick freezing'. If, instead of the usual slow refrigeration, freezing took place almost instantaneously, the crystals would not be able to grow. But how to freeze instantly? Many experiments were tried, even spraying the foodstuffs with liquid air, until a satisfactory method of instant freezing at about 30 degrees below zero was obtained.

'Quick-frozen' foods are still a comparative novelty, although they are widely used in the United States and are becoming increasingly available in Great Britain. The process makes it possible to purchase fresh strawberries, peas, or beans at any time of the year. 'Fresh' is quite an accurate term, in spite of the fact that they have been frozen, for neither the texture nor flavour is found to be altered noticeably when the foodstuffs are thawed. More important, perhaps, is the fact that it has been found that vitamins are not destroyed by preservation and that the method results in the public having the choicest parts of a crop. An enormous amount of laboratory research has been put into the founding of this industry. Another interesting development is the construction of buildings containing hundreds of 'quick-freezing lockers'. These

lockers can be rented by the public like safe deposits. The housewife will be able to make bulk purchases of perishable foods when they are cheap and store them in her locker until required. The gardener, instead of having a glut of some fresh vegetables in summer and none in winter, can store his surplus for use later.

Any industry must be well organized to be remunerative, and automatic machinery is now largely used. Those fresh strawberries at Christmas, not at the fabulous prices of hot-house berries but at a few pence a pound more than you would pay in July, can be made possible only by the application of many discoveries of science. For instance, in planting his peas the grower, who works in close conjunction with the freezer, must know almost to the day when they will be ready for picking. Left a day too long the pods would become tough. The freezer must arrange for his plant to be ready on this day, as well as for storage space or refrigerated transport for the peas when frozen. In some instances the freezing-plant is taken to buildings on the fields. In others a permanent plant is kept in the centre of good growing country. The saving of time between the moment of picking and the moment of freezing is important, in order that decay shall not even begin.

If we take the case of peas as typical, we find them being picked by hand or by machinery, which strips the pods from the plants, and in some instances also shells them, separating pods from peas. The peas are automatically sorted for size and floated in a salt solution to eliminate the over-ripe, which fall to the bottom. They may be subjected to steam for a short time to 'kill' the complicated chemicals which start fermentation. They are dried and packed in cardboard cartons which pass into the refrigerating chamber. Here the intense cold instantly brings their temperature down to 30 degrees below zero, and at this temperature they remain until, weeks or months later, they are taken from the refrigerator of some shop, handed over the counter to a housewife, thawed, and treated as the 'finest fresh-picked peas'.

Experiments have shown that, at a sufficiently low temperature, quick-frozen foods will remain good indefinitely. In Siberia, mammoths frozen by intense cold many centuries ago and preserved by ice have been dug up and found to be so good that steaks of meat cut from them have been eaten. Long-term preservation of food may become very important. At present a manufacturer would expect to freeze in the summer and dispose of his stock during the

following winter, but there is no reason why, with the increase of refrigerated storage space, crops should not be kept if necessary from year to year, enabling prices to be evened and the danger of famine eliminated. Refrigeration has the most important economic results, for it prevents alternation of glut and shortage which means that the grower is never certain what price he will receive for his crops. Food-preservation spreads the crops grown in a few months over the year and enables prices to be stabilized in so far as the scientist is concerned.

Each foodstuff presents its own problems to those engaged in its preservation. The storage of apples and pears, for example, is quite different from that of strawberries. These 'hard' fruits do not deteriorate so rapidly. Certain kinds will remain in good condition, with only the simplest precautions, for several months. This period can be considerably lengthened by special treatment and 'gas storage', a comparatively recent invention. The stores used are cooled, but not refrigerated, and success then depends upon the ventilation. Apples when picked continue to 'breathe' carbon dioxide, and in gas storage the ventilation is so controlled that the proportion of carbon dioxide remains correct over long periods. In this way apples can be preserved for a great length of time at comparatively small expense.

Two decades ago there was no gas storage, but now Britain alone contains about three million cubic feet of gas storage space, and the amount is being added to every year. This industry explains the clean, fresh apples you are able to buy after Christmas when those from your own garden, even if stored very carefully, become wrinkled and unappetizing. The same method will probably be applied to other foodstuffs such as broccoli, where it has been found that carbon-dioxide control can prevent the leaves turning yellow.

The long-period storage of fish is another problem which has now been successfully investigated. The ordinary method of preserving fish has been to pack it in crushed ice, but by this means the fish can only be kept for about twelve days. New methods of freezing are lengthening the time to weeks, and in one instance fish was kept in perfect condition for two years. With the necessity for trawlers going farther and farther afield for their catch this becomes of great importance. A suitable method of preserving herrings might solve the problem of what to do with this fish which is caught by the

million at certain seasons. Formerly, large quantities were salted, kippered, or preserved in some such way. Experiments are being conducted to discover a cheap and easy method of quick-freezing the herrings, so that gluts would be avoided and the fish made available in equal quantities all the year round.

The growth and importance of the refrigerating industry can be gauged from some figures. There are, normally, at least a thousand ships equipped with refrigerated chambers engaged in bringing food to Britain, and the value of this food is not less than £100,000,000 a year. The number of domestic refrigerators in the country is probably over the two million mark, and if we take the average figure that each saves half a crown's worth of food a week, we have a total saving of about £12,000,000 a year. The capital of the industry is over £80,000,000. Yet Britain is only one country, and although we rely on refrigerated ships more than other nations, we have nothing like the internal cold-storage equipment of the United States with its thousands of refrigerated motor-vans and railway trucks.

Refrigeration is normally limited to temperatures just above freezing-point for the preservation of food in domestic refrigerators, and to some 30 degrees below zero for 'quick freezing', but these are not the limits of low temperature which the scientist has made useful to industry. Experiments in very low temperatures began more than a century ago, and while those concerned may have had no idea that the discovery of methods of liquefying gases would be 'useful', these researches were pursued. From the theoretical point of view low temperatures have yielded rich results, ranging from laws relating to the behaviour of gases to information regarding the structure of molecules. With what may be called purely scientific benefits have come others of great commercial value.

The first liquefactions of gases at low temperatures were carried out by increasing the overall pressure, and this principle is still used. It was soon found that there was a critical temperature at which no increase in pressure could produce liquefaction. New means of lowering the temperature had to be found, and the most obvious of these was the rapid evaporation of a liquid gas already formed. The effect of rapid evaporation is to produce such a drop in temperature that the gas may solidify. This, in fact, is how one of the most useful products of low temperatures—'dry ice'—is produced. It is this substance which the ice-cream man uses in

his tricycle to keep his wares in good condition during a hot summer day. It is, in fact, not ice at all, but solid carbon dioxide.

'Dry ice' has many advantages over ordinary ice. Its lower temperature means that it lasts a great deal longer, and that a much smaller quantity is required to give adequate refrigeration for a given quantity of foodstuffs. To carry the same amount of ice-cream, depending for cooling upon ordinary ice, the tricycle would need three times the space and have such a heavy load that it would be impracticable. Another advantage is that solid carbon dioxide turns directly into gas without any intervening liquid stage, which makes it very convenient to handle. Its intense cold, however, makes it dangerous to touch with the naked hand, and you will find a warning to this effect in all these storage plants. The intense cold produces the same effect as intense heat—a burn. Paradoxical as it may seem, the effect of great cold on living tissues is the same as intense heat—they are broken down by the rapid passage of heat in one direction or another.

By mixing solid carbon dioxide, which he produced by forcing the liquid through a fine jet on to a non-conducting material, with ether Faraday managed to get down to about minus 230 degrees Fahrenheit. At this temperature ordinary thermometers are quite useless. Mercury becomes solid, and even the alcohol used for measuring lower temperatures is of no service. The chemist relies upon a gas thermometer, the expansion of the gas giving the temperature. Faraday sought to liquefy air, but was unsuccessful. It remained for Dewar, towards the end of the last century, to reduce air to a liquid. He used the same principles—the compression and sudden expansion of gases.

These experiments resulted in the foundation of several new industries of which perhaps the most important was that of obtaining oxygen from the air. We now use enormous quantities of pure oxygen, and a cheap supply is important. The source is all round us in the atmosphere, but it is mixed with a large amount of other gases. The gases are reduced to a liquid, which is really a mixture of a number of liquids, and this is then subjected to fractional distillation. In other words, the liquid is heated to the boiling-point of the least volatile gas, then heated to a little higher temperature, and then heated again to a still higher temperature. At each temperature one of the gases boils and is collected, so that the oxygen is separated from the nitrogen which boils at a higher

temperature. By very careful fractional distillation the 'rare' gases of the atmosphere, argon, neon, krypton, and xenon, are obtained.

Of these gases oxygen is by far the most in demand. More than a hundred million cubic feet of oxygen are liquefied every year for industry in Europe alone. It has many uses. Doctors require it both for the treatment of cases where breathing is weak and for combination with other gases as an anaesthetic. It is used for breathing by airmen flying at great heights, and the development of true stratosphere flying would vastly increase demands for it for this purpose. The largest quantities of oxygen in industry are probably used for the familiar oxy-acetylene blowpipe, and it is also necessary for a number of manufacturing processes. When it is to be used medically or for a blowpipe, oxygen is generally stored under pressure in heavy steel cylinders, but it is much more easily stored in a vacuum flask as a liquid because it then requires a lighter container, which is of particular value for aeronautical purposes where space is also a great consideration.

One of the little-known uses of liquid oxygen is in the preparation of an explosive. For this purpose it is soaked in charcoal and fired by a detonator. The explosion is due to the expansion of the liquid into a gas and the further expansion that takes place due to the heat generated. Oxygen has been used as an explosive for many years; it was used in boring the Simplon tunnel; but it has disadvantages from the military point of view that have made it unsuitable for shells or mines. Chief of these is that it can only be mixed shortly before use. If the soaked charcoal is kept long, the liquid oxygen evaporates. There is the further disadvantage that the explosive is extremely sensitive to a sudden blow. It would be detonated by being struck by a bullet and is unsuitable for the rough handling to which military supplies are liable.

In spite of rumours that liquid oxygen was the basis of a 'super-explosive' during this last war, it was not, in fact, used as an explosive, although it became increasingly important as a fuel for rocket missiles. It was used by the Germans in their V2 and in certain other rocket missiles, but the great heat of the flame when oxygen burns makes it less suitable as a 'fuel' than certain oxygen compounds, notably hydrogen peroxide, which is water with an extra atom of oxygen. Hydrogen peroxide was the favourite liquid rocket fuel of the Germans.

Liquid oxygen, however, continues to be an important explosive

for mining, where the military disadvantages are actual advantages. That it has to be prepared immediately before use shortens the time during which there may be accidental explosion, and that it rapidly loses its explosive strength means that if a shot misfires it can be left for a few hours for the liquid oxygen to evaporate when it will automatically become harmless.

Of the other gases obtained from the air, argon is used for 'gas-filled' lamps, owing to its lack of affinity for any other element. Neon is used in the familiar advertising signs. Xenon and krypton are not, at the moment, extensively employed. Helium can also be obtained from the atmosphere, but it is present in such minute quantities that to obtain it by fractional distillation of liquid air for such purposes as filling airships is not a commercial proposition. The helium used in the United States is obtained from 'natural' sources.

At still lower temperatures air becomes a solid and hydrogen a liquid. The last gas to turn to liquid is helium, liquefaction taking place at 450 degrees Fahrenheit below zero. This temperature is approaching 'absolute zero', the temperature which theoretically represents the limit of cold. Here we have passed beyond the regions used commercially to those dealt with only in the laboratory, but there may yet be another example of the fact that yesterday's laboratory experiment is to-morrow's industrial process.

You may ask why it is impossible to achieve temperatures of absolute zero. Non-technically, it is for the same reason that we cannot reach infinity. By exceedingly ingenious apparatus scientists have come to within a fraction of a degree of absolute zero. They will probably get nearer and nearer to it, but there will always be this fraction of a degree which separates us from an 'infinity' of cold.

Although we make no industrial uses of the temperatures round absolute zero, research into the behaviour of matter at such temperatures may be exceedingly useful to industry, particularly in the case of electricity. At very low temperatures great changes take place and many substances become almost perfect conductors of electricity and heat. At normal temperatures even good conductors reduce the amount of electrical energy they pass. An electric current in a long wire will eventually 'die out'. But at exceedingly low temperatures a current in a lead wire will continue almost indefinitely without much loss. In practice a current

passing through a conductor at a temperature approaching zero represents as near perpetual motion as we are likely to get. From these 'academic' researches may well come knowledge that will enable us to improve electrical transmission and reduce electricity bills.

Industry will also ultimately benefit from the new knowledge of the structure of matter that is being obtained by the use of very low temperatures. The speeding atoms are slowed down and scientists are able to watch them, as it were, 'in slow motion'. At present we may say that these experiments are of no more service to industry than was Faraday's first experiment in magnetism; but that one day they will be of the greatest importance, no one who has read the history of science can possibly doubt.

CHAPTER III

CANNING AND DEHYDRATION

AFTER refrigeration the most important method of food preservation of to-day is undoubtedly canning. This is the older method and is really no competitor of refrigeration. Against the disadvantage of the special preparation necessary and the fact that the food must nearly always be cooked while being canned, we have the enormous advantage that, once prepared, no special apparatus is required for keeping it in good condition. Tins can be stored anywhere for quite long periods, and in easily prepared special stores, almost indefinitely. Moreover, tins are very portable, whereas the transport of refrigerated foods calls for special vehicles.

Napoleon said that an army marches on its stomach, and he first realized the importance of a simple method of food preservation. He stimulated the research that led to canning; his object was purely military, and canning remains of immense military importance to-day. It would hardly be possible to feed a modern army in the field except 'out of tins'.

Nicholas Appert, who won the prize of 12,000 francs for a method of food preservation offered, among others, by Napoleon's government, did not really invent canning. His method was based on the discovery that heat could preserve food if the latter was afterwards prevented from coming into contact with the air by a layer of fat. It remained for Pasteur and others, very much later, to explain this effect and to found the safe methods of modern canning practice.

It was shown that the heat destroyed, or at least slowed down, the activities of the bacteria which brought about the chemical changes we call decay. It was inevitable that, during the period when canning was carried out more or less by rule of thumb, there should be mistakes and cases of food poisoning. To-day, when every cannery has its own laboratory, the possibilities of poisoning from tinned food are certainly no greater than from 'fresh' food exposed for sale in shops, and probably not so great.

Until comparatively late in the nineteenth century the canning which was carried out in the United States was largely a home industry. There were factories, but the methods were those of the home. The fruit or vegetables to be canned were peeled by hand,

the tins to contain them were made by hand, and the final sealing was carried out by hand. During this period canners realized that preservation would be more complete if a heat greater than that of boiling water could be used. This heat was obtained by increasing the water-pressure. The boiling-point of water rises with an increase of pressure, and it is thus possible to have water boiling at, say, 300 degrees Fahrenheit. The effect is not only to ensure better destruction of harmful bacteria and moulds, in other words, sterilization, but to cook the food in a shorter time. In modern canneries only a few minutes are necessary to cook and sterilize vegetables, fruits, or meats, the exact time varying with the nature of the foodstuff.

Canning really begins with the manufacture of the tins. These are not, of course, made of tin, for the simple reason that the metal is both too soft and too expensive for the purpose. But a tinned surface is excellent because of the resistance it offers to corrosion by the chemicals present in foodstuffs. Very thin sheets of mild steel are coated with tin by 'pickling them' and then putting them into a bath of tin. The layer is so thin that a pound of tin is sufficient to cover 25 square yards of steel sheeting. The tin-plate is lacquered to give further protection against the attack of organic acids.

The actual manufacture of the can is carried out nowadays wholly by machinery. A knife cuts the great sheets of tin into strips, the appropriate lengths are automatically cut off and each is rounded, the edges being bent over each other and soldered. The bottom is usually attached by making a lip all round the cylinder, dropping in the correctly shaped piece of tin-plate, and bending down the seam. The top, of course, is not placed in position until the can has been filled and sterilized. Although this sounds complicated, the ingenious machinery engaged in the work takes only a few seconds to complete a tin.

The cans then go to the filling-room. Here the foodstuff with which they are to be filled is already prepared. The preparation, in many cases, corresponds to that used in connexion with quick freezing. It is designed to ensure that no imperfect food is allowed into the can and to eliminate hand-labour as far as possible. The ingenuity of some of the machines is very great. For instance, the peaches which are canned by the million are peeled, halved, and stoned entirely by machinery. At all stages they are washed to

ensure cleanliness, not only for its own sake, but also because this is as essential in a canning factory as in an operating theatre and for very much the same reasons.

The cans are automatically filled with the correct amount of food as they pass on a conveyer under a reservoir of peas, peaches, or whatever it may be. A 'trap' in the container opens at the correct intervals to allow the proper amount of food to drop into the can, which then passes on to be filled to the brim with juice or syrup. In canning vegetables a mixture of salt and sugar solutions is used to make the 'syrup'. The filled cans are heated for a few minutes at a temperature rather below boiling-point to drive off the air in and above the syrup. The lids are then dropped into place and sealed. The cans pass to a super-heater, where they are 'cooked' for a period which varies from a few minutes in the case of fruits to an hour or more in the case of fish and meats. This kills the bacteria that may be present, and when the cans cool the condensing steam leaves a complete vacuum under the lid. Cooling is generally carried out rapidly in water, as this preserves the appearance of the canned food. Drying, labelling, and finally crating for the wholesalers are nearly all carried out automatically.

One of the advantages of canning is that it makes food cheap. The peaches which you buy canned would cost three or four times this sum if fresh because they would either have to be grown in a hothouse or brought many thousands of miles in very careful packing under great risk of spoilage. Canned food is only cheap because the industry is mechanized and well organized. In its early days canned food did little more than offer the possibility of eating delicacies out of season. The cost was often as high as for the fresh food in season. Cheapness has been brought about by the design of machinery which can deal with enormous quantities of food very quickly. Apart from the machines used for picking vegetables, we have machines such as those which seal the cans at the rate of 100 a minute, the huge cookers dealing with 1,000 cans at a time, the skin-peeling machines which may deal with a hundred crates of peaches in a minute, the machines which core, peel, and 'chunk' pine-apples at the rate of 100 a minute, and many others.

Every industry is dependent upon science, but none more than canning, which was really born in the kitchen. Constant tests for bacteria and airtightness are made, and, apart from routine work in

ensuring the quality and appearance of the tinned foods, scientists in the cannery laboratories are constantly dealing with the problems presented by new foods. When tinned foods could no longer be attacked on the grounds that they were unsafe, they were opposed for the reason that they were not 'nourishing' and lacked the vitamin content of fresh foods. Canning does not necessarily destroy the nourishment of a food any more than cooking. It is certainly true that high temperatures destroy some vitamins, to the extent of about 25 per cent., but no one has ever advocated a diet entirely composed of tinned foods, and chemists are still experimenting with various methods of replacing the lost vitamins. The canned food of the future may have the correct dose of synthetically prepared vitamins added to its normal content.

Canning has opened up new possibilities for the fruit farmer. He can sell his crop in advance and be certain of a stable market. In normal times something over 70,000,000 cans of fruit are prepared every year in Britain. These call for about 75,200 tons of tin-plate and 30,000 tons of fruit. The range of canned foods is considerable, embracing about 160 different kinds of meat products, 50 kinds of vegetables, and 30 of fruits, as well as innumerable types of soup. Some canners place an entire meal, meat and vegetables, in a single can so that picnickers or busy housewives can do all their cooking with a tin-opener. It is a comparatively new industry, but it is one in which mechanization is the main key to success.

The third great method of preserving food is by dehydration, which has the advantage over refrigeration and canning that it not only preserves food over long periods, but also greatly reduces it in bulk and weight so that storage and transport are facilitated. The principle of dehydration is that the water is extracted at the point of origin. Without moisture the chemical and bacteriological processes we call decay cannot take place. The water is added again before use, restoring the original substance of the foodstuff. The results of the process have become familiar during the war, when dehydrated foods saved millions of tons of transport and played a vital part in feeding nations and their armies. So long as they are protected against moisture, dehydrated foods do not normally require special containers.

The amount of water in the normal foods we eat is tremendous. A ship carrying potatoes and fruit is, in fact, loaded with perhaps

8,000 tons of water and less than 2,000 tons of carbohydrates and other chemicals. Water is the one 'food' that is available in almost unlimited quantities everywhere, and it seems uneconomic that we should carry it about the world.

The method of extraction of the water varies with each food and is by no means simple, for the water has to be extracted without the remaining substance being burned or spoiled. The principle generally used is that of extraction in a partial vacuum under a high temperature for a very short time. In many instances 'infra-red' heat has been found successful. Discovery of successful methods of treating many different kinds of fish, meat, fruit, and vegetables, as well as milk and eggs, has called for a great amount of scientific research. It is not sufficient that the chemical contents of the food should be restored when water is again added. It must be reasonably palatable. The most successful foods to be dehydrated have been milk and eggs, and it is likely that even when the abnormal conditions resulting from war have disappeared, they will continue to be used as a means of absorbing gluts and of distributing foods economically over the world.

The scientist has recently made another important contribution to the production of food. He has shown how to convert food from one form into another, so that the amount of food is increased. An interesting example depends upon the production of a yeast which feeds on molasses. The yeast provides a food rich in proteins, an essential and vital part of our diet. The yeast is, in fact, a 'meat', and, in the factory, the scientist carries out in a few hours a process for which the animal requires many months, itself consuming much food in the meantime. It is not suggested that anyone will now prefer 'yeast meat' to real roast beef if the choice is available, but where the total amount of food available is very limited the number of people who can be fed from a given amount of vegetable food is greatly increased by converting it into protein artificially instead of 'naturally'. The possibilities of making purely synthetic proteins of real food value exist, but are still not fully realized.

CHAPTER IV

THE AGE OF METALS

THE variety of useful articles that industry can provide for mankind and their suitability for the purposes for which they are intended are very largely dependent upon the materials available to the manufacturer. Primitive man had to rely upon six or seven metals at most, and a few simple alloys made of two or more of them. Even a century ago the number of metals available was very small. To-day there is an almost unlimited choice. Indeed, rather than, 'Now I wonder what metal would be best for this article or piece of machinery', the manufacturer can say, 'I want a metal with certain exact qualities', and he expects the metallurgist to provide it for him.

And he is not often disappointed, whether it is a metal that weighs half as much as steel but does not tarnish in sea-water, or one that is as strong as iron yet is a good conductor of electricity. Where the early maker of metal articles had available one basic material, the modern manufacturer can choose the most suitable from thousands. The change that has taken place can be appreciated from the statement that your motor-car has perhaps twenty different metals in its construction, and as many as eighty alloys of widely varying characteristics.

This great expansion in the choice of materials is due not only to the discovery in the laboratory of a number of metals which were unknown even two hundred years ago, but also to the science of combining these metals, not chemically, but physically, in those mysterious things we call alloys.

Indeed, it may be said that nearly every metal we use to-day is an alloy, for absolute purity in a metal is both extremely expensive and, in most cases, not very desirable. Metals, curiously enough, are the better for their impurities, but the metallurgist must make certain that only the desired 'impurities' are present and that they exist in the correct proportions. We speak of steel as a metal, but it is really an alloy of iron and carbon and other metals. In practice, 'steel' is a no more definite term than 'flower'. There are thousands of different steels, the only thing that all have in common being iron as the largest ingredient. The same applies to the ancient alloys of brass and bronze which are now prepared in many different forms for different purposes.

It would be impossible within the bounds of a single book to describe even a small fraction of the innumerable alloys now produced, but there are a number of comparatively new metals which science has presented to industry, and some of their alloys will illustrate the rich field of materials upon which the manufacturer can draw. Many of these metals were laboratory curiosities only a few years ago. The discovery of relatively easy methods of separating them from the ores, or of their unique value for certain purposes, has made these substances available in large quantities at reasonable cost. They have left the laboratory bottle and become the raw material of many industries.

Thirty years ago few people had heard of the metal titanium. To schoolboys it was just a symbol in the list of atomic weights, and not very important at that. The 1914–18 war brought some demand for the metal, for its tetrachloride reacts with water to produce a smoke. This was used for smoke-screens, and when peace came it was discovered that the fine particles of the oxide made an excellent pigment for paint, being unaffected to the same degree as lead by sulphur fumes and having great powers of scattering light. A little titanium oxide goes a long way, and this makes it a particularly valuable pigment for certain purposes, such as impregnating rubber to make it white and impregnating paper to make it opaque.

It is probable that the air-mail paper you use owes its opacity, in spite of its thinness, to the presence of titanium oxide. In the case of rubber the value lies in the fact that pigments will not stretch, so that it is important to use the smallest possible quantities of them for colouring. It is this same quality that causes titanium oxide to find its way into artificial silk stockings. Women do not like their silk to be shiny, so small quantities of minute particles of titanium oxide are used to take out the shine, without spoiling the stretch of the silk.

No doubt as titanium becomes available in larger quantities other special uses will be found for it. At present it is still quite rare, for although there is more of it in the earth's surface than there is of many commoner metals such as lead and copper, the ores are scattered and not found in rich pockets.

Manganese and chromium are two other metals about which your great-grandfather heard little. To-day they are used in combination with iron to form hundreds of valuable alloys.

Manganese gives steel certain qualities which make it very desirable, particularly for armaments, and chromium is the metal which makes steel 'stainless'. The strength and other qualities of the alloys depend on the exact percentage of the metals used, and a difference of one-tenth per cent. may produce a metal that is different in almost every way.

Tungsten is another comparatively 'rare' metal which is employed in the manufacture of steel; without it we could not have tools of such astonishing hardness that they will cut ordinary iron and steel like cheese. It is also the secret of your electric lamp filament, where its unique quality of being able to withstand high temperatures, even when drawn into very fine wire, is of the greatest value. We have only to place the brilliant light of a modern electric lamp with its tungsten filament against one of the old 'carbon' lamps to see the value of the present which science has made to the electric-light industry. Most modern lamps consume actually less current in spite of this brilliant increase of light, but intensive research upon methods of illumination which may do away with filaments altogether and effect still greater economy in current has been successful and is described later in this book.

To return to the metals alloyed with steel, the example of molybdenum is interesting because few people have ever seen this metal. Yet it is safe to forecast that there is an appreciable amount of it not very far away, for molybdenum is one of the secrets of the hard-wearing steels in every car. Twenty years ago this metal was rarely heard of in industry although it had been known to science for many years. Now, many millions of pounds of the metal are used annually. It is used to toughen steel in objects as varied as armour-plate for battleships and crankshafts for cars. The qualities which this substance imparts to steel when alloyed are difficult to describe non-technically, but it may be said that molybdenum enables a steel to be hardened without danger of its cracking, to be heated to higher temperatures for toughness, to keep its strength even when subjected to high temperatures for long periods, and to have a uniform hardness throughout rather than at the surface alone. Yet the amount of the metal required is only five pounds to each ton of steel. Using very much more molybdenum, a different alloy is produced with the remarkable quality of remaining hard when red hot. This makes it particularly useful for high-speed cutting tools.

When, as the result of the demands of the steel industry, molyb-

denum began to be available in large quantities, other uses were found for it, and it is now employed in the manufacture of dyes, in pottery, and as a catalyst. It is a particularly effective catalyst, and this has led to the hope that it may eventually enable us to increase the efficiency value of certain fuels. An interesting use for molybdenum and tungsten is as points for telegraph instruments and sparking-plugs Formerly, silver was used for telegraph instruments and platinum for sparking-plugs, but these new metals give equally satisfactory results and much longer life

Vanadium is another metal incorporated with steel to form valuable alloys. The particular quality it imparts is that of fine grain. Nickel, of course, was one of the first of the rarer metals to be used in steel, giving it ductility. Owing to the huge amount of tough steel used in armaments, the world's consumption of nickel has risen enormously. It is interesting to recall that when nickel ore was first discovered five centuries ago by prospectors looking for copper, they cursed it as useless. It has been said that 'the devil is in nickel', because of its war-time use, and the position of nickel shares has been taken as a 'barometer' of world peace. But to-day nickel has many uses. The steels are used by the whole automobile industry and for locomotive parts where ductility is an advantage. Large quantities are also used for nickel-plating

If we leave steel for the moment and consider the alloys of another common metal, copper, we find an equally remarkable change taking place Until quite recently almost the only alloys of copper were bronze and brass. Now copper has been alloyed with a whole range of substances giving a number of entirely new products. It was found that the combination of a little phosphorus with copper produced a metal which cast well and resisted corrosion better than the pure metal. To-day, phosphor bronze is used where toughness and resistance to fatigue, corrosion, and wear are required in combination The propellers of many liners are made of this alloy.

Another copper alloy is nickel silver, sometimes called German silver. This is an old alloy which has been greatly improved, and it is now used for a vast number of articles from surgical instruments to zip fasteners, its great advantage being that the polish it takes does not easily show finger-marks Combined with the comparatively rare metal beryllium, copper gives a remarkable alloy which is exceedingly hard, but does not spark like steel. This makes it of

unique value for tools used in places such as explosive manufacturing plants where a spark might have dangerous results. The strength of this alloy and its resistance to fatigue make it valuable for switches and many other electrical parts. It has also been found useful as a substitute for another copper alloy, silicon bronze, in bearings, owing to its remarkable elasticity. A spring made of this metal can be bent and released almost indefinitely without showing signs of fracture. In one test ten million 'bends' were given without harm resulting

An interesting alloy is one of bismuth, lead, tin, cadmium, and indium, the last a rare metal which not long ago cost £60 an ounce, but is now very much less expensive. This alloy was probably originally suggested by type-metal experiments and has the low melting-point of 116 degrees Fahrenheit or a little above blood heat. It is thought that, apart from other uses, it might be valuable for making casts of parts of the human body, electro-plating making the cast permanent. Quite a number of metals have special uses for medical or surgical work. An alloy of copper, nickel, and tungsten is nearly half as heavy again as lead, and this quality may lead to its being valuable for protection against X-rays or radium emanation.

In all likelihood there is no metal which has not many potential uses It is the task of the chemist to prepare the metal from its natural ores and then to devise a commercial method of extraction on a large scale as soon as industrial uses are found. There are still some metals of which use is restricted owing to ore scarcity or difficulties of treatment. But every year these metals are being found new work, and as soon as they become industrially 'invaluable' for a certain purpose the scientist is nearly always able to produce them in large quantities.

Of the rare metals for which industry has found use during the last few years, rubidium is a peculiar metal of the alkali group which has very special uses in connexion with photo-electric cells. Its low melting-point would be a disadvantage for most of the purposes we associate with metals, but it is often a point in its favour when a metal is needed for the emission of electrons.

Another metal, little used at present, but which, because of its remarkable properties, may enable wireless valves of gigantic size to be built, is 'columbium'. Tantalum, yet one more rare metal of olden times, has a very high melting-point, but tungsten is preferred for electric lamp filaments. When tantalum becomes avail-

able in quantity it may be of tremendous importance, for it is almost impervious to acids and would be welcomed for this reason by the chemical engineer.

But perhaps the most remarkable instance of scientists making available a whole new range of materials is afforded by aluminium. Aluminium was not obtained at all until the nineteenth century, although it is one of the most widely distributed of all elements. Then it remained a laboratory curiosity, costing almost its weight in gold, until almost simultaneously Charles Martin Hall in the U.S.A. and Héroult in France discovered a method of extracting it from its ores electrically. The price of aluminium came down to a phenomenal extent, and industry was able to use this highly important metal. Pure aluminium has little strength, but it can be coloured, heat treated, and so altered in its ordinary characteristics by the addition of other substances that there is scarcely any use to which it cannot be put. It can be made almost as strong as steel, it can be hardened, used as paint, made non-corrosive, and even employed as a heating agent where great temperatures are required. To-day, thousands of articles are made of aluminium or aluminium-magnesium alloys. We may well be at the dawn of an aluminium age, for lightness allied with strength can save many millions of pounds in a year.

Much of the power used in our road transport is wasted in unnecessary friction and in lifting useless weight up every hill. In a large liner the actual weight of passengers and goods carried is almost negligible compared with the weight of the ship, and huge engines are needed to drive this mass of steel. Suppose the total weight of the liner, its fittings, and cargo could be reduced by one-half. If all our trains, motor-cars, and trams could undergo a course of slimming, fuel bills might almost be halved. Aluminium and magnesium alloys offer that possibility. Already they are used in the new, fast, stream-lined trains and for parts of ships; the new *Mauretania*, for example, has aluminium funnels. Aluminium alloys make possible the high piston speeds of the modern car. They are used for almost every conceivable accessory in all aeroplanes, and often for the main structure. It is scarcely too much to say that aluminium has made flying progress possible. This metal is gradually being applied to architecture; it may soon be extensively applied to our personal needs and may ~~even help to reduce the physical~~ effort needed, to take one example, in the moving of furniture.

Lightness is only one of the characteristics of aluminium that have brought it such a wide use. Being non-corrosive, an excellent conductor of heat, and a good electrical conductor, it has come into almost universal use for electric cooking utensils and ordinary electric gear. It reflects light and radiates heat, hence its use on radiators or for decorative purposes. It is easily obtained in the form of finely divided particles, and therefore makes a paint with remarkable spreading and leafing qualities It is worth noting that now that methods of obtaining many metals in finely divided form have been developed, they are being increasingly used as paints. Copper, chromium, zinc, and bronze are a few of the metal paints available, the thin layers giving the surfaces coated many of the characteristics of metal.

Another light metal, once a laboratory curiosity, became of immense importance during the war. Pure magnesium is of little use, except, perhaps, as an incendiary and for use in photo-flashes But alloyed with other metals, magnesium gives us metals which are nearly as light as aluminium and a great deal stronger and tougher. Early in the war the Germans showed what could be done by the use of magnesium in aircraft and tanks, and our engineers had to revise their ideas, as well as their estimates of the quantities of magnesium that would be required for war production By the use of magnesium alloys it was found possible to save up to 1,000 lb. in a four-engined aircraft, a weight that could be used to carry more freight, whether of fuel, bombs, or more peaceful cargoes.

Some idea of the increased use of magnesium can be gathered from the fact that in the U.S.A. one new plant alone had an output greater than the entire United States consumption before the war. In Britain we were in a difficult position regarding magnesium. We had been in the habit of importing the metal and we were cut off from our sources by war just at the moment when we needed greatly increased quantities. Once again science came to the rescue. We have no substantial deposits of workable magnesium ores in Britain, but our coasts are washed by the sea, and the sea is an inexhaustible source of magnesium. The amount averages only one part of magnesium in 800 of sea-water, but this means that a cubic mile of sea will yield hundreds of tons of the metal.

Suitable positions were found for plants into which millions of gallons of sea-water a day could be pumped. Here the water was treated and pumped back into the sea, minus most of its magnesium

salts The principle of the treatment is that the sea-water is filtered and passed to a tank where finely ground lime or calcined dolomite is added. Magnesia is precipitated and the deposit slowly settles out. The water is filtered away and the magnesia is then dried, ready for the extraction of the metal The reduction is carried out by mixing the oxide with coal and other substances and roasting it while chlorine gas is passed through the mass Molten magnesium chloride is formed and a heavy electric current produces pure magnesium with the release of chlorine. The gas is passed back, so that the process is, theoretically, regenerative.

Magnesium is important, not only as a metal, but in chemical combination when it is used as a lining for furnaces and for other purposes where resistance to very high temperatures is required. Large-scale production has brought the price down to about one-twentieth of that ruling only some thirty years ago, and magnesium alloys have now become an 'everyday' material. When the secret of making them resistant to the normal corrosive food substances is mastered they will be largely used for the production of sauce-pans and other utensils.

There are still some metals available in large quantities for which sufficient use cannot yet be found. Mercury is one of them This, the only liquid metal, is used for detonators, for extracting gold, and in a large number of valuable drugs, but the supply exceeds the demand. Those producing it, some years ago, offered a large prize for anyone who could suggest uses which would absorb the large possible output, and there is little doubt that in time science will find that the unique characteristics of mercury make it an improved material for the manufacture of a much-needed article or for use in some industrial process.

One of the most wasteful things on earth is rust. If we call it corrosion, it is a thing that is suffered by almost every metal in the open air It has been estimated that rust costs the world hundreds of millions of pounds a year in replacing lost metal and in painting for protection. The answer that science has given to this is stainless steel, but it is not a perfectly satisfactory alternative. Stainless steels are more expensive and cannot be produced with every quality to be found in various ordinary steels. The time may come when a suitable stainless alloy can be found for every purpose, but at present some method of coating the steel with protective material seems the most practical where large special parts are concerned.

Plating of various kinds is used for this purpose, one comparatively new process allows the metal to be impregnated as well as coated This means that chipping of the coat does not open the way to corrosion, for the protection extends for a very considerable depth.

Although only a few metals have been mentioned, it is abundantly clear that science has supplied industry with an astounding number of new materials. The difference between the beginning of the last century and the present time may be summarized thus Formerly, the manufacturer in metal would say, 'I need a metal of so much tensile strength, so much weight, so much resistance to wear.' Then he would search among existing metals or alloys for those with the most desirable qualities. Generally a second or third best was chosen. To-day, he can have metal 'made to measure'. Metallurgists can produce for him an alloy of almost any required qualities. The problem to be faced is usually the cost of 'the best'.

CHAPTER V

PLASTICS

ONE of the greatest gifts of science to industry is that of new materials. For the greater part of history men were content to use the natural products they found at hand wood, clay, and such metals as could easily be extracted from their ores by heating. These materials have their limitations. wood is inflammable, subject to decay and to the ready absorption of moisture; metals are heavy, they conduct heat and electricity, and have many other qualities which, while admirable for certain purposes, are disadvantageous for others.

Since the 1914–18 War we have seen the growth of a huge industry built up entirely on new materials; not 'discovered' by science, but 'created' by its aid. These substances have been called plastics, a name that is perhaps not altogether correct, for their chief characteristic is that, once finished, they are seldom pliable. Americans sometimes term these materials resinoids or synthetic resins. Most people are familiar with a number of natural resins, notably shellac, and many of the synthetic resins are similar products in appearance and texture, but they possess many highly desirable qualities, such as resistance to heat, which are lacking in the natural product.

These synthetic resins are entirely products of the laboratory. Their history is older than most people imagine. The first plastic was really celluloid, which was prepared nearly eighty years ago by synthesizing gun-cotton with camphor. Ten years later a better plastic was produced from cellulose acetate, and before the end of the last century another plastic had been produced from urea and formaldehyde. But it was not until 1907, when Dr. Baekeland, the brilliant Belgian chemist, working in the United States, produced a synthetic resin called bakelite, that the modern industry was founded. Even then it hardly began to develop until after the 1914–18 War. In 1922 the world production of plastics was about 7,000 tons. Three years later this had doubled. Since then the industry has grown so rapidly that it is hardly possible to keep pace with the figures, but in all probability 7,000 tons does not represent a single month's production. The annual turnover of the industry in Britain alone in 1939 exceeded £20,000,000

and when reconversion is complete it will probably be very much greater

Bakelite is prepared from carbolic acid and formaldehyde. Substances closely allied, such as cresol, may be used instead. Both these substances are liquids, yet they finish the process together as a hard solid which is difficult to cut and impermeable by liquids The manufacture consists of two distinct stages: preparation of the resin, mostly by chemical means, and moulding into the desired shape, which is almost entirely mechanical

The first step is heating of the cresol and formaldehyde solutions together. As in so many chemical reactions, the process is helped by a catalyst, a substance which is able to assist a chemical change, although it does not itself take part and although only a very small quantity of it may be needed. The result of heating is a mixture of water, several other substances, and a resin. The water is filtered off and the resin dried.

The new resin is now ready for turning into the desired shape, it may be for an ash-tray, it may be for sheets of material for use in insulation, or for hundreds of other purposes This is carried out in three chief ways. The resin can be poured into a mould and given permanent form by heating under pressure. The soft material which is so easily affected by heat before treatment becomes hard and unaffected by anything but very high temperatures. The products are afterwards shaped and polished. Or the resin may be crushed, mixed with a 'filler' such as wood flour, asbestos powder, fine metals, or mineral dust, and then moulded into hot formers under high pressure, to emerge, after treatment, with a high polish, requiring no further working. In yet another method the resin is used to impregnate layers of some fabric, such as canvas, which are pressed together to form a substance of great toughness. This can be cut and shaped like metal.

These processes are, in brief, those by which a wide class of synthetic resins, called 'thermosetting', are prepared and shaped. It is impossible to go into details of the chemistry of each, for apart from the great complication this varies so widely. But we can obtain some rough idea of what happens when two liquids form substances of such great strength, hardness, and general resistance to water or heat. The comparatively simple molecules of the original substances, only comparatively simple because phenol has the formula C_6H_5OH, link with each other under heat and pressure

until molecules of tremendous complexity have been linked up into great tenacity.

Perhaps the reaction will be clearer if we imagine scattered groups of three or four soldiers being attacked by cavalry. They are unable to resist very long, for the cavalry ride in between, attacking them from all sides. But suppose the groups of soldiers joined up to form a compact square. The attacking cavalry would not be able to filter in, and would find the loosely linked soldiers, although still individuals, very hard to attack in a body. If we suppose that our phenol and formaldehyde molecules are the soldiers and that they are moulded into a square synthetic resin, we have some idea of why these substances are so strong from almost every point of view. The chemistry of synthetic resins is still rather obscure, but it has been estimated that some of the resins have molecular weights as high as 100,000.

There is another type of synthetic resin, the 'thermoplastic', which is not moulded or laminated before the substance is formed, but pressed or worked into the required shape like clay and then given permanence by heating. These 'thermoplastics' are, perhaps, the most widely used, for most of the vast numbers of articles used to-day are prepared either by the moulding of the substances under pressure with a 'filler' or by lamination.

What are the great advantages of plastics over other materials? First of all is the comparative ease with which they are shaped Articles varying in size from the head of a drawing-pin to a complete motor-car body can be pressed out one after another. For some of the stronger articles heating may be necessary for as long as an hour, but for most it is a matter of a few minutes or even seconds. Then there is the fact that they finish with a high polish. Wood usually needs elaborate polishing and constant repolishing. The plastic article is 'born' polished and will retain its gloss almost indefinitely, requiring, at the most, washing to remove grease and dirt.

Although plastics require no actual polishing, most of them will take a dye very easily in the manufacturing process and can therefore be used for decorative purposes. The dye is generally incorporated at the grinding stage, when the dried resin is reduced to powder and mixed with a filler. Almost any desired colour can be produced, and it will be absolutely fast. Moreover, methods of mixing dyes enable attractive designs of colours which 'run' into

each other to be produced. These dyes are so firmly fixed in the substances that they do not affect the taste of food served on plastic dishes. The plastic itself resists the attacks of such acids as are found in food and of alkalis of moderate strength

Then we have the individual properties of the different plastics. Some, like bakelite, are remarkable for their insulating properties and form a good substitute for glass or rubber in electrical apparatus. Perhaps the word 'substitute' is not correct, for it generally infers something inferior, whereas plastics have electrical properties equal to the older insulators, and other properties, such as strength and permanence, vastly superior. Some plastics are valued for their great tensile strength, which may be as much as 12,000 lb per square inch, others for their heat-resisting qualities, or for their transparency.

Transparent plastics are not, of course, any more transparent than glass, but they have none of the brittleness of that material. This was what made celluloid valued in the early days of its production. But the new plastics, sometimes called 'flexible glass', have the advantage that they are non-inflammable. They have unique uses, varying from the windows of aeroplanes to the barrels of the 'visual' fountain-pens that enable you to see how much ink remains in the pen. Another advantage over glass held by these transparent plastics is that they weigh much less, a property almost as valuable as flexibility in, for instance, aeroplane windows

One of the transparent plastics produced in Britain has optical properties closely resembling those of crown glass, and admits the passage of rays well into the ultra-violet range. Yet it is exceedingly tough and for all practical purposes unbreakable. It weighs about half as much as glass and it can be machined easily without any danger of splintering or cracking The uses of such a plastic are wide, but the material is not always so well able to resist scratching as ordinary glass.

A very wide range of articles is now made from plastic. In any ordinary living-room are found ash-trays, candlesticks, door-knobs, telephone, vases, electric-light switches, plugs, and sockets all made of plastic. The wireless set probably contains quite a number of different parts moulded from plastic, admirably suited to this purpose because of its insulating properties. In your motor-car you may find the dash panel, some of the door mouldings, and other parts made of plastic.

As progress is made in this remarkable industry, larger and larger articles will be made of plastics. The disadvantage of the high cost of plastics and of the special steel dies needed to mould them is overcome, with large objects, by the process of lamination. In this, alternate layers of wood, paper, or other suitable material and plastic are built up to the desired shape and size and then treated by heat and pressure The result is a bonding, the two substances entering into partial combination and giving great strength. The process is very different from that of making the ordinary 'ply-wood' in which the glue remains a distinct layer.

Bonded plastics were the secret of the lightness of the Mosquito aeroplane, and it was this high strength-for-weight ratio which gave the Mosquito its astonishing performance. With the high strength-for-weight ratio goes the advantage of a very smooth and highly polished surface that is weatherproof and requires no paint or protective covering. This absence of paint can add 5 or 10 m.p.h. to the maximum speed of an aircraft.

Small craft have been moulded from plastics in the same way, giving lightness with great strength and a pleasing finish not corroded by sea-water.

Some of the greatest progress has been made in the production of plastic fabrics. These are in great variety and have certain advantages They are generally waterproof and therefore not easily stained, they can be cleaned by wiping with a damp rag, they do not fade in sunlight, and they take brilliant colours and keep them, since the colours are not 'dyed in' as with ordinary fabrics but form an integral part of the material. These plastics are made like others, except that they are rolled out in flat lengths. They are not woven fibres like ordinary textiles. For clothing, with the exception of waterproofs and aprons, they have certain disadvantages, but for upholstery, curtains, tablecloths, and so on they have enormous advantages. Although so many plastic fabrics are already being made, we are at the beginning rather than the end of the plastic fabric era.

The properties that can be produced in plastics are extremely varied. On the one hand we have soft fabrics, and on the other a plastic as hard as steel that can be used for making dies and jigs. We have transparent, hard plastics from which lenses for cameras or 'contact' eye-glasses can be moulded and we have elastic, rubbery plastics. Synthetic rubber, whose manufacture I shall

describe later, is a plastic and one of the most important. By combining plastics with other materials we get unique materials Sheets of cotton fabric laminated with plastic give a material of great strength and hardness with certain advantages when used in machinery. For instance, car bodies of this material would not squeak and clockwork constructed of it does not 'tick' but is quite silent. A method has been found of incorporating colloidal graphite in plastics so that they are 'self-lubricating' Bearings of plastic have been made which require no oil, a great advantage in certain cases where access is difficult.

Those who only know plastic in the form of ash-trays and domestic equipment find it difficult to credit that it can be prepared in forms having great strength and with wearing qualities almost equal to steel. Gear-wheels have been cut from plastic and have proved as hard-wearing as steel. Mr. Henry Ford said some time ago, 'The day may not be far off when we shall grow most of a motor-car on the farm' He was referring to the production of plastic materials from such substances as cotton and sour milk. The raw materials for the resin can be obtained from vegetables and their fibres used for the filler or strengthening fabric, so that the whole of the growing plant is used

An interesting group of plastics is made from casein, obtained from milk. There is a story that these plastics were discovered when a cat chasing a mouse in a laboratory knocked over a bottle of formaldehyde which fell on some cheese. The chemist next morning was surprised to find his cheese had become as hard as iron; and thus casein plastics were discovered. But this may only be a fable. Casein is now made by 'junketing' milk with rennet, removing the fat, drying it, and then treating with formaldehyde. This, of course, only produces the synthetic resin. The subsequent manufacture into various articles and the hardening process are carried out simultaneously as with other plastics. One of the casein plastics produces the beautiful synthetic marble which is much used for decorative purposes. Real marble, of course, is mostly calcium carbonate. The synthetic marble is a sodium caseinate, but it is good enough to suggest that, with increasing knowledge, synthetic materials may eventually revolutionize the whole of industry as we know it to-day.

CHAPTER VI

COAL

BRITAIN'S industrial prosperity was largely built up on coal. Because good coal was easily mined and provided a cheap source of power it was possible to develop all types of manufacture which required cheap power. Coal was so easily obtained that it has been treated with a carelessness and lack of scientific method not found in any other industry. What manufacturer of silver, for instance, would take an ore containing gold and silver, extract the silver, and throw away the gold on the plea that he was only concerned with silver, or that there was plenty more of the ore to be obtained?

This, in effect, is what we do with a large amount of the coal we burn. Heat is one of the least important products of coal, yet every year many millions of tons of coal are destroyed for nothing but the heat which they can yield. Even this heat is not scientifically used. Probably 70 per cent of the heat from a coal fire, instead of going into the room which it is supposed to be warming, disappears up the chimney, together with smoke which is really fine particles of carbon, and many other products of great industrial value. What is left, the ashes, we throw into the dustbin as useless. The fire produces dust in our rooms and dust in the air through the smoke. We have to spend money on disposing of the contents of our dustbins. Having wasted a few million pounds' worth of chemicals by pouring them into the air, we then spend a few more million pounds repairing the damage done to our buildings by the pollution or in paying for the delays and inconvenience caused by fogs. Compare this with the scientific use of coal in a big motor-works where 250 tons of coal provide heat and leave only a hundredweight or so of ashes.

An open coal fire is really a miniature gas-works run on exceedingly unscientific lines. Most coal consists of the compressed trunks and leaves of vegetation which flourished in an age when sunlight was very plentiful. When we burn coal we are really 'borrowing' the heat that was falling upon the earth many millions of years ago. But the plants contained a very great deal more than heat. The changes wrought by compression and decay made available in a useful form a number of chemicals, and coal is, therefore, one of the greatest reservoirs of raw materials known to civilization.

Almost the only constituents of coal we use when we burn it in an open fire are the volatile gases. These are driven off by heat and burn with the yellow flames we know so well; yellow because we only partly burn the gas, the carbon, and a thousand other chemicals contained within the coal. It is this heat which eventually makes the coke, formed by partial combustion, incandescent, and that too is partly consumed. To extract a small quantity of heat from a lump of coal we destroy some ammonia that might be used to fertilize our gardens and a considerable amount of the mixture we call coal-tar, from which can be manufactured thousands of chemicals varying from aspirins to dyes and plastics.

In the scientifically organized gas-works many of these products are saved, and we still get the heat. In the first gas-works the prime consideration was the production of coal-gas, a mixture of volatile hydrocarbons, to provide light. The light is no longer important, for few people use a naked gas flame, and with the incandescent gas mantle it is the heat that matters It is therefore possible to 'strip' the gas of these valuable hydrocarbons and to substitute water-gas, made by driving steam into incandescent coke, which burns with an almost colourless flame but great heat. The gas which we burn to-day is very different from that which lit the streets a century ago.

The application of science to the gas industry really began when scientists realized the possibilities of synthesis, that is, the building up of chemicals from simple products. Coal-tar, the heavy substance driven off when coal is heated in closed retorts without air, provides many very valuable chemicals, so numerous that it is only possible to mention a few. There are crude benzol, naphtha, phenol, toluene, cresol, anthracene, naphthalene, as well as the pitch with which we treat our roads, ammonia, carbon, and innumerable others. From these chemicals we make drugs, dyes, synthetic essences, and many other substances. Coal-tar is the starting-point for saccharine and aspirin, to mention two very familiar examples.

The products obtained depend upon the method of treatment, but from a thousand tons of coal, which even housewives of a small town might burn in a week, scientific treatment can obtain over 210 tons of gas and 1,000 gallons of coal-tar. In special apparatus the benzol is 'stripped' from the gas by the use of activated carbon and can be used directly as a motor fuel. By special treatment the

1,000 tons of coal can be made to yield 600 tons of liquid fuel, or petrol.

In recent years coal has been proved to be an even more valuable source of raw materials. The great synthetic industries have been built on coal-tar, which represents only a few gallons per ton of coal. New ways of using the coke, which is produced at the rate of about 700 tons for 1,000 tons of coal, have opened up vast possibilities.

From coke we can make water-gas, and instead of burning, it can be used to make methanol, which in turn is converted into formaldehyde, one of the basic substances required by the plastics industry. In special plants water-gas is combined with hydrogen and turned into an amazing range of products from fats to lubricating oil, by the processes of synthesis or hydrogenation. Coke plus limestone plus heat supplied by electricity gives carbide You are probably familiar with this substance for use in your bicycle lamp Water added to carbide gives acetylene, which burns with a bright flame and is used in large quantities for high-temperature flames for cutting steel But calcium carbide also yields far more important products. Indirectly it can be built up into alcohol, acetic acid, ether, and ethylene, which in turn help us towards plastics, synthetic rubbers, and artificial silk by a comparatively simple process.

At the beginning of the century, when one new chemical after another was produced with coal-tar as the starting-point, many began to think that all was known of the wonders of coal, but now a completely new view can be taken of the situation. Coal can do much more than warm us; it can supply almost every want of human beings from clothing to food. The time may come when the substance we now burn so carelessly will be treasured as one of the most valuable sources of raw material for manufacture, and the idea of burning it for its heat will seem as ridiculous as lighting a fire with Treasury notes. The process which Perkins began when he discovered mauve, the first of the synthetic aniline dyes and the basis of a great industry, is still going on; science has not yet explored all the possibilities of this amazing substance with which we so casually fill our scuttles.

It will be many years, however, before we can do without coal as a source of heat. We know that our coal supplies are limited, and, moreover, every ton of coal costs money to extract from the

ground. It is therefore important that we should obtain our heat or energy from coal as cheaply and as easily as possible What happens at the moment is that the coal is mined and then carried by sea or rail to the gas-works, perhaps several hundred miles away. The more scientific method would be to extract the gas at the pit-head and distribute it through large pressure mains. This would eliminate a large number of small gas-works at which it is not worth while recovering all the valuable by-products. Laying gas mains is expensive and, of course, considerable power has to be used in pumping the gas; but the principle of the 'gas grid' is making headway.

Instead of obtaining power from coal in the form of gas, we can use the heat to drive a steam-engine, which in turn drives a dynamo generating electricity, the most easily distributed form of energy Great power-stations should, of course, be at the pit-head, feeding a grid supplying the whole country. It seems fantastic to convey coal hundreds of miles in trucks when the part we want in our homes, the energy, can be extracted at the pit-head and distributed so simply by a wire

Science has given its attention to coal-mining which, after all, is the basis of the whole coal industry. Where miners used to hew every ton of coal with the most primitive tools, to-day in the up-to-date mine they are provided with power in the form of compressed air, and can bore holes for explosives or saw out great sections of the coal in minutes where hours were required. Mining is a difficult, dangerous trade, but there is no reason why, with the continued application of scientific methods, coal-mining should not become reasonably clean and safe. We know now that the dust formed is not only wasteful but exceedingly dangerous, since it is as explosive as the 'fire damp' and ruinous to human lungs. Air-conditioning on a large scale could eliminate danger and relieve these trying conditions. The continual danger of falls and explosions makes the application of power in coal-mines more difficult, but scientists are at work devising instruments that will automatically detect the presence of gas and give warning, and substituting steel for timber in an unending fight to improve this vital work.

Coal is now cleaned and sorted largely by automatic machinery, dust being extracted and the shale removed. The waste products are removed by making use of their different weights, which register as the coal passes along a conveyer and result in their being

tipped out. Dust is useless for ordinary purposes, but new ways of utilizing it are being found every year. It can now be satisfactorily burned in special furnaces, and the time may come when coal in the form of dust will be generally preferred. Very fine coal dust can be made to work an internal-combustion engine of the Diesel type; it can be mixed with oil, or applied to various oil-conversion processes.

One interesting development that may be mentioned here is the idea of utilizing the energy in coal without extracting it from the earth. In coal-mining we dig coal at considerable danger and expense, simply to obtain energy in the form of gas. Why not take this gas from the coal without bringing it up to the surface? In principle this is fairly simple, all that is required being the ignition of some of the coal underground to produce heat to drive off gas from other parts of the seam. In experimental plants oxygen and steam are fed to the coal face, and the gas drawn through a shaft to a gas-works, where it is treated in exactly the same way as usual, the ammonia, tar, and other by-products being recovered. This process was begun in Russia in 1931 and five or six plants are now at work. The gas contains a considerable amount of water-gas which is utilized for power and for building up synthetic products. The method saves enormous sums in transport and mining, but it has certain disadvantages. A great deal of the coke and a certain amount of other by-products are wasted, so that it would be, at present, only justified with mines containing a poor quality of coal. On the other hand it might enable seams that would otherwise be unremunerative to be worked. In Britain one of the great disadvantages would be the danger of subsidence of the land into the seams after they had been emptied, for in this country little has been done to remove dwellings from the close proximity of mining areas

A number of causes during and immediately after the war have combined to demonstrate dramatically the importance of coal and coal-mining to the ordinary man and woman. A greater scarcity of coal and a higher price for it at least have the advantage that they stimulate research into the most economic methods of use and mining We are only beginning to apply a really scientific technique to coal-mining. There is no reason, except cost, why a coal-mine should be much different from a tube tunnel When we consider the changes that have taken place in, say, transport and

communications, coal-mining is still in the eighteenth century. At the same time, coal is becoming more and more valuable as a raw material for chemical industry, and the time may come when we shall consider burning coal simply for its heat like burning a house to roast a pig. Coal-mining and its attendant industries, far from being 'on their last legs', are still capable of vast development, and, guided more by long-term science and less by short-sighted finance, may be at the beginning of a new era of usefulness and prosperity.

CHAPTER VII

SYNTHESIS: SCIENCE WORKS WITH CHEMICAL BRICKS

SYNTHESIS is a word which we often misuse in these days. We talk of 'synthetic emotions' and even 'synthetic beauty' when, of course, the adjective we should really use is 'artificial'. But perhaps the frequency with which we employ the word is an indication of the very important part it plays in our lives. Synthesis is rapidly becoming the very life-blood of industrial chemistry, and it is certainly destined for an even more important place in the near future.

What does the term 'synthetic' applied to a material mean? It implies that the product has been built up from simpler substances, and not obtained by extraction from a natural source. The drug quinine, for example, which the modern doctor finds almost indispensable, can be obtained either by the extraction of the natural substance from cinchona bark or by building up its complicated molecule from more simple substances in the laboratory. The important thing to remember is that the ultimate substance is the same in either case, so that it is quite wrong to use the adjective 'synthetic' in a disparaging sense. 'Natural' quinine and 'synthetic' quinine are virtually the same substances in every way. In one case Nature has performed the synthesis by a long and complicated process, using the earth, the air, and sunshine as its raw materials. In the other, the synthesis has been performed in a comparatively short time in the laboratory If both substances are purified, it is impossible to distinguish them by chemical analysis.

In exactly the same way pure sugar obtained from beets or the sugar-cane is the same in every way as sugar built up in the laboratory from carbon, oxygen, and hydrogen. There are certain very interesting examples of materials which, seemingly identical, differ in their response to the passage of light-beams, so that the product of nature and that of the chemist are identical only in chemical composition. Their physical state varies. Other compounds are so complex that complete analysis is hardly practicable. Sea-water is one instance. Artificial sea-water does not apparently possess all the powers of the sea itself, which still defies every attempt at imitation.

The adjective 'synthetic' is often loosely applied to other products which are not in fact built-up versions of natural products, but substitutes for the 'real thing'. Synthetic rubber, for example, is not the same as the rubber made from the ordinary juice of the tree. It is not rubber at all, if the term 'rubber' is to be precisely defined and not applied to any substance which has certain qualities of elasticity We hear of synthetic wool and synthetic leather, and here again, however excellent these products of the laboratory may be, they do not chemically bear much relation to the hides and wool of sheep. Artificial silk, although in many ways it physically resembles the natural product of the silk-worm, differs from it chemically, and the term 'rayon' used by scientists is really a much more correct description. It must always be borne in mind that the word 'synthetic' is, therefore, used in two senses. 'Substitute' is not the strictly accurate interpretation.

In dealing with coal, mention has been made of the vast number of substances that can be built up from coal-tar, one of the great starting-points of synthetic chemistry. But another is the air, a raw material which the world possesses in almost unlimited quantities and which is free for the taking. The air contains carbon, nitrogen, and oxygen, and the fourth element vital to so many substances, hydrogen, is easily obtainable from water. With these four elements alone it is theoretically possible to build up many hundreds of thousands of different substances At the present moment the most important synthetic products obtained from the air are 'nitrates'.

Whereas the world used to rely almost wholly on the great natural nitrate deposits of Chile for its fertilizers, it now obtains a large proportion of them by the synthesis of the elements in the air and in water. Nitrogen is taken from the air and hydrogen from the water to form ammonia, with the aid of coal and catalysts such as iron oxide or molybdenum. These catalysts, incidentally, enter into most synthetic processes, and, although no one fully understands their action, they are extremely important. They assist a chemical action to take place, although they themselves remain unaltered at the end of it.

Nitrogen products are synthesized from the air by several different methods. In one, an electric spark is used, nitrogen and oxygen combining to form nitric oxide which dissolves in water to form nitrous acid. Nitrates are formed naturally in this way by

every flash of lightning, the flash being Nature's gigantic spark. Nitrogen products are also obtained from ammonia by heating it with air, platinum gauze being the catalyst.

Some of the greatest feats of synthesis have recently been performed with wood and air as the starting-points. Wood provides cellulose; from this, with nitrogen and ammonia, the chemist builds up nitro-cellulose. This was formerly chiefly important as a smokeless explosive, but to-day it is only a step in the synthesis of other products. Nitro-cellulose itself, like cellulose acetate, dissolved in suitable solvents, is extensively used as 'dope' and as a quick-drying paint. The shiny surface of your car is synthetic. The great advantage of these synthetic products over the older paints is the speed with which they can be applied. Where it used to take weeks to paint a car, to-day it is done in a matter almost of minutes.

With the aid of nitro-cellulose is made a host of synthetic materials, from artificial leather for bookbinding to stain-proof tablecloths By treating the nitro-cellulose with caustic soda and carbon disulphide the chemist builds up viscose, which when squeezed through a narrow slit produces the flexible, moisture-proof, transparent wrapping which to-day has so many uses. If, instead of a slit, a tiny hole is used for the projection of the viscose, artificial silk or rayon is produced. The synthetic strand is little thicker than that of the silk-worm, and when woven is very strong From the viscose, by treatment with other chemicals, we can produce a spongy substance which has the advantage over ordinary sponge-rubber that it can be made into any shape.

In this particular branch of synthetic chemistry there is the advantage that the additional substances used can themselves be produced from the simplest elements. Caustic soda, for example, can be synthesized from salt and water, and carbon disulphide from coke carbon and sulphur. The chemist taking the elements as his bricks builds them up into an immense number of different patterns, all containing the same elements in varying proportions, but completely different in their physical appearance and properties.

If, instead of treating the wood pulp or cellulose with nitrates, acetates are used, we obtain cellulose acetate, the starting-point for an equal number of remarkable products Cellulose acetate is the basis of many plastics as well as rayon. If we must compare the natural with the synthetic product, we might well take real silk and acetate rayon. We should find that the synthetic product

can be made into a cloth that is comparatively stainless, is very resistant to the action of sunlight, and dries quickly; a few definite advantages which it has over the natural product.

Still taking wood as his starting-point, the synthetic chemist has produced a range of materials which suggests that a human being could, if necessary, live entirely on 'wood', using it to give him shelter, clothes, food, and many materials Sawdust treated under controlled conditions of temperature with sulphuric acid yields a sugar. By fermentation this sugar can be turned into alcohol which is the basis for many syntheses and one of the most important raw materials of chemical industry. The sugar can alternatively be used to feed a yeast to produce proteins, or it can be purified and made fit to eat. Before the war German chemists produced chocolates made entirely from wood or coal Normally, of course, it is cheaper and easier to obtain the sugar from cane or beet. The alcohol may be used for the manufacture of synthetic rubber or it can be made to yield glycerine or acetone, two chemicals which are the bases of yet another group of synthetics, from high explosives to paints.

Synthetic chemists have revolutionized the production of textiles. To use sheep for turning grass into fibres suitable for spinning and weaving is really very wasteful. The sheep have to be fed over a long period. A machine does not consume a great deal of the raw material fed to it merely in 'staying alive'. To-day, synthetic alternatives to the traditional fibres of wool, flax, and cotton can be produced from a variety of sources. Rayon uses cellulose as the raw material. It is dissolved in acetone and then ingeniously spun through very fine spinnerets. The threads can be made as thin as the finest silk or thick enough for carpets. The introduction of rayon has revolutionized fashions, particularly for women. Half the world would have to devote itself to silk-worm rearing to produce enough 'natural' silk to provide them with their needs; it would clearly be quite impracticable. The rayon industry gives a substitute at a lower price, with certain disadvantages, but with many advantages at the same time.

Another synthetic thread is the plastic nylon which can be produced from a variety of the great basic chemicals of synthetic chemical industry. It is elastic and water-repellent and has actual advantages over natural silk. Its strength was demonstrated during the war when it was used for parachutes and glider tow-ropes.

The third group of synthetic textiles is made from casein and the

products were extensively used in Germany and Italy as wool substitutes. Protein fibres have great potentialities, but they have certain disadvantages when compared with natural wool, of which the chief is loss of strength when wet. The commonest raw material is skim milk, but many proteins can be manipulated to give fibres.

With all these synthetic fabrics, there is competition with the natural product, decided by the relative cheapness and qualities. As with synthetic rubber, the best results are often obtained by using a mixture of the natural and synthetic products to get the best qualities of both. A rayon–wool mixture can give cheaper blankets Rayon woven into natural materials can give permanent creases. Casein fibres mixed with natural mohair, cotton, or rayon can reduce the cost and produce new effects; one of the mixtures gives a synthetic 'fur' for felt hats.

Possibilities are almost limitless, for the chemist can control his materials; he is not dealing with qualities which are largely decided by nature before they reach his hands, as in the case of cotton and wool. There is another great advantage enjoyed by the synthetic product: it is independent of the weather. A few days' rain can make an immense difference to the wool produced by many millions of sheep. Drought can destroy cotton. But the chemist in his factory can turn wood, milk, seaweed, or whatever it may be into cloth regardless of the weather outside.

Coal is a synthetic material which nature has taken several million years to make. The chemist can make it in the laboratory in a few hours. He takes the same raw material as nature, cellulose in the form of plants, and subjects it to great heat and pressure, the equivalent of years of decay or of earth movements, so that when it cools he has coal. There is no advantage in the manufacture of coal in this way, for the heat that has to be applied is, of course, greater than the heat derived from the combustion of the subsequently produced coal. The experiment was performed in Germany, largely as a demonstration of the way in which man can to-day imitate Nature's synthesis at a million times the speed.

The greatest field of synthesis at present is still, perhaps, in the field of drugs. When you read of the discovery of a new cure for some disease, you must remember that behind it may be the story of the careful synthesis of a completely new substance in the laboratory. A few atoms are added, or rearranged, and a new drug is made available for medicine. It may be of little use or it may

prove, like the sulphonilamides, mecrapin and D.D.T., a really potent weapon in the conquest of disease. In building up new drugs chemists no longer work completely in the dark. They know the therapeutic effects of certain groups of chemical compounds, and they seek to construct new compounds which will have definite qualities. To this branch of synthetic chemistry we owe all the hundreds of different drugs we now use for killing pain, from aspirin to the barbiturates, as well as many others used for killing germs. In the past drugs have been used chiefly for helping the body to resist the effects of an attack by germs, but now a new branch of medicine is making strides in which the war is carried into the enemy's camp and the germs are poisoned by chemicals introduced into the system. Most of these chemicals are purely synthetic, and although they do not occur in Nature at all, their discovery will probably rank in importance with the discovery of antiseptics or anæsthetics. Synthetics as a science is turning the chemist into an architect of materials which may revolutionize the world of industry as we know it to-day.

CHAPTER VIII

SCIENCE MAKES RUBBER

It is difficult to assess one group of synthetic products as more important than another Drugs, dyes, plastics, they are all so necessary that if the synthetic products in them suddenly disappeared we should find it an unhealthy, drab, and uncomfortable world. But the production of the synthetic rubbers is of special interest and importance. Interest because here were a group of substances most deliberately produced by the chemist for industry when the supply of the natural product was restricted, and important because industry now has the means not only of obtaining rubber-like substances in virtually unlimited quantities, but of controlling their exact properties in a way never possible when only the natural material was available. The story of synthetic rubber also admirably illustrates the general history of any synthetic product.

It is wrong to speak of synthetic rubber for, in fact, there are a great number of synthetic rubbers made from different raw materials and having very different properties. They have in common that their molecules have a tendency to 'hook together', thus giving them those characteristics of resilience and elasticity which we describe as 'rubbery'. The synthetics have no chemical resemblance to natural rubber, except in so far as the physical properties of both substances are due to the structure of the molecules and the fashion in which they hang together.

The enormous demand for rubber that came with the progress of the motor-car stimulated research into the possibilities of producing synthetic chemicals with rubber-like physical properties, although it was not until the world was swept by a phase of 'self-sufficiency' that research became intense. There was plenty of rubber; so much that the tapping and planting of trees was artificially restricted. But it was in the possession of a limited number of countries and others did not wish to be dependent upon them for raw material. The early work was done in Germany as part of her self-sufficiency programme in preparation for war. Later, when Malaya, producing the greater part of the world's rubber, fell into the hands of the Japanese, Britain and the United States carried out intensive research into synthetic rubbers. Gigantic plants, capable of producing

as much as the whole world's production of natural rubber in 1939, were built in the United States. Germany, unfortunately, had previously been ridiculed for her work.

Research chemists did not seek to make the chemicals contained in natural rubber synthetically. If we are making synthetic sugar or synthetic quinine, we must seek to build up exactly the same molecule as the natural product, for it is the chemical and physiological effects that are required. Saccharine has the sweetness of sugar, but no one would call it 'synthetic sugar'. In the case of rubber the circumstances are quite different. It is the purely physical qualities such as elasticity and toughness which make rubber valuable. Chemists therefore tried to build up molecules which, while having a very different chemical formula from that of natural rubber, would have the same physical characteristics.

They have found four important groups which give substances with much the same response as natural rubber. These groups are called bunas, butyls, thiokols, and ethenoids, the first group being by far the most important. The raw material is a substance called butadiene which can be made from a variety of agricultural products, from crude petroleum, from natural gas, or from acetylene which can, of course, itself be synthesized from coal. Which raw material is used depends very much upon what is available at the spot. At normal room temperatures butadiene is a gas, but it becomes a liquid under pressure. The process by which it is transformed into Buna-S is known as polymerization, a condensation of smaller molecules into bigger ones. This word describes an extremely elaborate process which calls for high pressures and temperatures, with a maze of pipes, tanks, and other apparatus covering many acres. The production of the rubber substance is only the first stage. The processing of this rubber is equally elaborate and important. Finally, it is produced in different forms convenient for the manufacture of tyres or other rubber articles in very much the same way as the natural product is manufactured.

Butyl rubbers are produced from the gases produced in petroleum refineries and thiokol is produced from ethylene gas, which is a by-product of petroleum and which used to be burned in huge quantities as a waste material.

The first synthetic rubbers were comparative failures. We all remember the stories of the German military vehicles equipped with buna tyres which had a life of only 500 miles. But chemists

persevered, and gradually the quality was improved until at last it was possible to produce a synthetic rubber with wearing qualities more or less equal to that of natural rubber. It was tyres, above all, for which rubber was wanted in the war and it was therefore upon synthetics that would make hard-wearing tyres that research was concentrated. During this work a number of other 'rubbers' were produced which, while possessing good elasticity, had additional useful properties not found in the natural product Natural rubber has certain disadvantages; it is, for example, adversely affected by contact with oil or grease and it deteriorates rapidly in sunlight or extremes of heat and cold.

It was soon found that some of the synthetic rubbers were far more resistant to oil and grease; so resistant, in fact, that they could safely be used for making flexible hose for carrying these substances. This was a great advantage, for here was flexibility with resistance to corrosion. Some of the synthetics were more resistant to heat and cold, making them even better than natural rubber for certain purposes in aircraft Butyl 'rubbers' are extremely resistant to chemicals, making it possible to use them for parts of chemical plant where natural rubber would be useless. During the war synthetics were used for gas-masks because they are well able to resist mustard gas.

Thus, the chemists who had begun the search for a 'substitute', something that would serve to tide over a crisis, ended by producing a whole new range of materials with unique properties of their own, as well as many of the ordinary properties of natural rubber which have made it so valuable. The new 'rubbers' can be used in such industries as petroleum storage and refining, brewing, and printing where natural rubber would rapidly be destroyed by corrosion.

From this arises the question of competition by various types of synthetic; will there be a 'battle' between the natural and the synthetic product? In practice, experience shows that the expected conflict seldom occurs. It is true that the production of synthetic dyes virtually superseded the considerable industry dependent upon natural dyes. But rayon did not replace silk and synthetic rubbers are not likely to ruin the natural rubber industry. Up to the present it has been found that for many purposes, notably tyres, an admixture of the natural rubber with synthetic gives the best results.

Further, the new characteristics of various synthetics greatly

increase the field in which rubber can be used. Much depends upon the prices at which natural and synthetic rubber can be produced. At present the advantage is with natural rubber and this may be maintained for some time by more scientific methods on plantations and refineries. Yet one more point is that much of the success of synthetic rubber has been due to the processing of the product. The same amount of scientific research devoted to the processing of natural rubber will extend its many possibilities. Some of these results can already be seen. In the early days of motoring the life of a tyre was only a few thousand miles To-day, it is a poor specimen that does not last for 30,000 miles The difference is due entirely to scientific research devoted to improvement of the natural product

As far as the general public is concerned, it is probable that in many cases they will not be aware whether they are using natural rubber or synthetic rubber. But the coming of the synthetic rubbers will bring greater comfort and convenience. By bonding synthetic rubber with steel wire it has been found possible to make a water pipe suitable for plumbing in ordinary houses. This may mean the end of burst pipes due to frost. At the other extreme, rubber has been processed to be so soft that it is 'downy' and, in fact, is used as a kind of artificial 'mother' in incubators for chickens.

CHAPTER IX

OIL: LIQUID GOLD

WHEN we speak of oil to-day we generally mean the mineral oil from which we obtain petroleum, and upon it all the air and most of the road transport in the world depends. Because it is only found in a limited number of places, and because the supply is limited, and it has been estimated that oil-wells may be exhausted in two generations, scientists have been busy trying to find alternative sources of this vital substance. They have produced motor fuels from a variety of other raw materials, but natural oil is still supreme, and as each year science is showing industry how to make better use of its products, the world's supply becomes much larger than had been estimated The discovery of natural oil in Britain during the war is an example of the increase in the world's resources made possible by scientific methods.

Petroleum consists of a mixture of substances, all of which have in common the fact that they are built up of carbon and hydrogen atoms, hence the name hydrocarbons. Oil is formed in the earth over the course of millions of years by the action of great temperatures and pressures on vegetation or minute animal life. It collects in underground 'pockets' or lakes. To extract the oil man has to bore down to the lake, when the oil gushes up under the immense pressure of the natural gases and of the earth's upper strata.

The oil industry began very casually, and except for burning in lamps or stoves no one thought very much of the volatile hydrocarbons in oil until the coming of the internal-combustion engine. Oil is absolutely essential for this type of prime mover, the lighter liquids to provide the fuel and the heavier for the lubricants. The oil industry to-day uses scientific methods at every step, and in recent years the direction of progress has been towards improving natural oils by breaking down or building up their constituent molecules.

The first step is to detect the presence of oil under the earth, for the pockets are found only in a comparatively few places. The scientist does this by studying the formation of the rocks, knowing that certain formations are most likely to be oil-bearing. In these days he uses delicate instruments which detect minute differences in the magnetic permeability of the rocks or in the way in which

they carry or reflect vibrations. A seismograph, the instrument used in recording earthquakes, is used to follow the direction of explosion waves from a charge fired deep in the earth, and the engineer is able, as it were, to X-ray the ground. While he may not be able to state with certainty that there is oil underneath, he can indicate strong probabilities and estimate the depth at which it may be found.

The next step is to drive a small hole down to the pocket, and this is carried out by boring-tools suspended on flexible shafts. Research has provided the hard steel to make tools that can cut through rock with ease, while improved methods enable greater and greater depths to be reached every year. As each section of the hole is bored it has to be cased with steel to keep out moisture and to retain the oil. The pressure which the casing has to withstand at very great depths is tremendous; it may be in the region of 100,000 pounds. Some of the problems of deep boring can be realized from the fact that the temperature rises above the boiling-point of water, and that the bit of the drill, revolving at perhaps 200 times a minute, itself generates tremendous heat which only the finest steels can withstand. These problems have been successfully overcome, as also those of keeping the well straight and removing the waste cut away by the bit. As it collects, mud is pumped down through the hollow drill to come out at the bottom, lubricate the bit, and then come up again bearing with it the debris. When hard rock or a hollow tempts the drill off the straight path, a camera may be sent down to bring up a picture of what is happening, and the drill brought back into place with deflecting-tools.

Wells have been bored to below 12,000 feet, and theoretically there is hardly any limit to the depth that could be reached. But even in a two-mile hole there are many thousands of lengths of pipe coupled together, and the cost of boring may be £100,000, so that there is an economic limit below which it does not pay to go. This is, at the most, about three miles. It is interesting to note that on a scale model of the world as big as a house, the depth of the deepest oil-well would hardly show as a dent in one of the bricks.

When a well is first tapped the oil rushes up under the great pressure of natural gas. Many barrels may be wasted before the well is brought under control. Gradually this pressure is reduced, and it ceases to be sufficient to lift the oil long before all the pre-

cious liquid has been extracted. Several methods are used of increasing the flow. Gas under pressure may be forced down the well so that it mixes with the oil and brings it up as a spray. Another method is to flood the oil-bearing sands with water which is pumped off, bringing the oil to the surface. Undoubtedly as a shortage of oil begins to make itself felt more use will be made of methods that extract the last possible drop from the well.

The raw oil is forced into pipes which carry it to the refinery, for as it comes out of the ground it is a dirty mixture of substances of no use for anything. Oil is now carried great distances in pipes, it being much more economical to send the oil along a pipe from refinery to sea-coast than to pump it into barrels and carry it by road or rail. In North America alone there are over 70,000 miles of pipes carrying about 300,000,000 barrels of oil a year. In the Near East the greatest pipe-line in the world, over 600 miles long, carries 4,000,000 tons of oil a year from the isolated spot at which it is found to Mediterranean ports. The tremendous extent of the oil industry can be gauged from the fact that this line cost about £10,000,000 to lay, and yet is an excellent investment. From these ports and those of the United States, Mexico, Venezuela, and other countries where oil is found, it is conveyed in tankers to all parts of the world.

Oil is refined by the process of distillation which is so often used for separating liquids. The crude oil consists of a number of different liquids and solids each with its own boiling-point. By gradually raising the boiling-point and collecting in different containers the substances which turn into vapour at each point, the oil is separated into its constituents. Almost the first substance to be given off is petrol, the lightest of the commercial oils, which has a very low boiling-point. The vapour is condensed, and this, the most valuable constituent, collected. Actually, petrol itself consists of a mixture of hydrocarbons, and these are collected at temperatures varying from below the boiling-point of water to nearly 400 degrees Fahrenheit. These different liquids are afterwards blended to give a good fuel for internal-combustion engines.

After the petrol comes paraffin oil, familiar to everybody for burning in stoves and lamps. There are several kinds of oil which distil at varying temperatures, and they may all be blended for the various purposes for which they are required. Then comes off a substance called gas oil, a good deal heavier than petrol, and used

largely in these days for improving coal-gas. It is treated in gas-works to give 'carburetted water-gas', which improves the quality of the so-called coal-gas. At the bottom is left fuel oil, burned in the furnaces of ships in place of coal. It is this substance which heats the boilers of oil-fuelled vessels and which may be used in jet engines for aircraft.

When distilling is carried out at these temperatures fuel oil and petrol are by far the biggest products obtained, each yielding about 35 per cent. of the original crude oil. But by varying the temperatures of distillation the scientist can change the products obtained. If distilling is carried out at a high temperature nothing is left but a coke which can be burned like that obtained from coal.

The petrol distilled off is not ready for the market, for it contains many impurities damaging to engines, the chief of which is sulphur. These are removed by treatment with chemicals. By treating the fuel oil it is possible to obtain waxes and the heavy oils which are used for lubrication The process is delicate, calling for exact control of temperature. The fuel oil is heated until a heavy vapour comes off. This is a mixture of wax and heavy lubricating oils from which the wax is eventually separated by passing it into a very cold chamber, where it solidifies. The lubricating oil is then redistilled further, to separate the different substances, although it requires considerable purification before it is ready to do such wonderful work as preventing the piston of a motor engine tearing itself to pieces by friction against the walls of the cylinder.

It might be worth considering here what a lubricant actually does in an engine. When two substances rub against each other there is always friction. However smooth their surfaces may appear to the naked eye, they would appear rough under a powerful microscope. The lubricant forms a thin wall between the two metal surfaces so that one can pass against the other in safety. Actually the two surfaces never touch, the film of oil acting as a roller-cushion between them. How thin is this cushion can be judged from the fact that although an engine may hold several pints of oil, not more than a thimbleful will be in use on the walls of the cylinder at any given moment. This film is all that stands between a car ready to travel thousands of miles without trouble and an engine that is little more than scrap iron. An immense amount of scientific work has been carried out on the working of lubricants, and as a result it has been possible for the industry to

provide the motorist with oils that are far better suited to the modern engine than any nature ever made.

To return to the oil refinery, the wax is utilized for candles and other purposes and, in fact, hardly a drop of the original crude oil is wasted. The modern refinery uses scientific methods in which much of the temperature regulation is done automatically. Much more petrol is now obtainable from a given amount of crude oil by the principles indicated in modern research. The oils with a higher boiling-point may be 'cracked' to make them lighter and suitable for motor fuel. The actual molecules are broken up to take on a new character. The cracking is carried out in stills which are able to withstand very great pressures, and the oil is simultaneously subjected to a temperature of somewhere near 1,000 degrees Fahrenheit and a pressure of about 750 pounds. Some oils are still further improved by a process of hydrogenation in which a hydrogen atom is added to the molecule of the compound.

Another way in which more oil is obtained is by treating the natural gas which comes up from the wells. Formerly this used to be allowed to escape and waste, but now it is trapped, cooled by compression, and the liquid squeezed out. Or it may be passed over oil which absorbs the petrol. The petrol is afterwards distilled off. About 2,000,000,000 gallons of petrol a year are now obtained in this way from the gas which was formerly wasted. It is even lighter than ordinary petrol and suitable for aeroplane engines. In many cases it is blended with ordinary petrols to improve their characteristics.

Very little of the fuel used in internal-combustion engines to-day is 'natural'. The chemist has shown how the natural hydrocarbons obtained from petroleum can be altered to give fuels which have a much greater power-conversion value. The high performances of modern cars and aircraft would be impossible on 'natural' fuels. Quite early in the development of the internal-combustion engine designers found that the amount of compression they could obtain was limited by the phenomenon of 'knocking'. By research into the causes of knocking, including the very high-speed photography of explosions inside a car cylinder, technicians discovered that knocking was due to a kind of premature explosion of the fuel under compression and they conceived the idea of altering the fuel to render this effect innocuous.

In the first instance 'anti-knock' dopes were added. These

were chemicals, the addition of which in very small quantities enabled greater compression to be used and thus more power obtained. The addition of these dopes added greatly to the performance of the ordinary car in acceleration, maximum speed, and miles per gallon. But it was found that there is a limit to the 'doping' of fuel and scientists turned to the possibilities of re-arranging the molecules of the petrol by means of high temperatures, great pressures, and catalysts. They began to produce fuels with higher octane ratings. The octane rating of a fuel represents its anti-knock qualities in terms of octane gas; a good 'natural' motor spirit might be octane 65, a good anti-knock fuel up to octane 80. Before 1939 small quantities of 100-octane fuel were being produced. Under the pressure of war, mass-production methods and the tremendous equipment required were developed. Plants covering many acres began to produce 100-octane fuel for allied aircraft by the million gallons. The enemy were unable to produce fuel in quantity with such a high rating and this gave allied aircraft an advantage, although the injection system on many German aircraft to some extent rendered them independent of lighter fuels. Direct injection gives very good engine control and avoids the evaporation difficulties of fuel at high altitudes. It is not possible to burn 100-octane fuel in an engine designed for a low octane fuel, but if it were the 100-octane fuel would give a typical plane a maximum speed of 24 m.p.h. more, an improved ceiling of 2,000 feet more, a 75 per cent. increase in the rate of climb, and the ability to carry a greater maximum load. The 830-h.p. engine would become a 1,050-h p. engine without any increase in weight.

Now, 'better than 100-octane' fuels have been developed, and when mass-production methods and plant have been devised commercial aircraft will be able to travel faster or carry greater loads. Theoretically it should be possible to improve the performance of 'natural' spirit to the point where one gallon will enable an average car to travel 250 miles. Such perfection is not likely to be attained, but in time we may consider 100 miles to the gallon an ordinary performance. High-compression engines of the Diesel type or gas turbines may also supplant the earlier type and in this case the high-octane fuels will probably be employed in other ways. The modern engine is, to an extent, built 'round the fuel' just as fighter aircraft are constructed for their armament.

Then, with oils for lubrication, it is possible to improve their characteristics by making them oilier. By using high pressures and temperatures in hydrogenation the molecules can be so altered that they give the metals they are to cover the maximum protection while remaining liquid at fairly low temperatures and not too fluid when hot. In many cases small quantities of various chemicals are added which work into the minute indentations in the metals and fill them up. The addition of these chemicals may give the film of oil far greater strength, in one case, for example, raising the film strength from 5,000 to 18,000 pounds to the square inch. While the oils are oilier they are not so sticky, which means that the motorist can often use a lighter grade and therefore obtain more miles to the gallon out of his engine by the direct reduction of frictional losses.

The science of oiliness is very important to-day when so many wheels go round. Wherever you see a piece of machinery moving, there, you can be sure, oil is required, and its quality may decide the efficiency of the machine or the length of its life. The nature of oiliness is not yet fully understood, except that the oil molecules do not mind what shape they are pushed into, and that they act as buffers, sticking to the steel but not to each other. As we learn more of the chemistry and physics of oils we shall gradually reduce friction. Oilier oils are doing for friction what streamlining has accomplished for air resistance. Oil in its many forms is still one of the most important materials in the world.

CHAPTER X

SCIENCE MOVES US ABOUT

TRANSPORT has become one of the great industries of the world. We take it so much for granted, thinking little more of going into an office to book a passage to New York than of jumping on a bus for a penny ride, that it is easy to overlook its vastness. If we take the motor and railway industries alone and consider the following facts which are true of an average normal year, we may have some appreciation of the astonishing ramifications of the transport industry, which is the biggest in the country, already employing some 2,000,000 men and women.

The railways of Britain carry about 1,150,000,000 passengers a year over their 21,000 miles of lines. The weight of the goods carried is about 250,000,000 tons a year. To provide fuel they require over 14,000,000 tons of coal a year, and annual purchases are made on the scale of 11,000 tons of paint, 21,000,000 bricks, and 1,000,000 tons of ballast.

There are about 179,000 miles of roads in Great Britain, and they carry 16·4 vehicles per mile. They contribute about £90,000,000 a year in revenue, while since 1910 the total taxation on motor vehicles and fuel has been a billion pounds. The total number of motor vehicles in the world now exceeds 40,000,000. Yet less than fifty years ago there were only a few score motor vehicles in the whole of America.

Of greatest interest are some of the more recent inventions and discoveries concerned with transport. If we take first of all the railroad systems, we find that two important things have happened during the last few years to prove false the prophets of fifty years ago who foretold the end of railways. It was perhaps understandable that when the competition of the motor-car, not to mention the bicycle, began to make itself felt, people should have jumped to the conclusion that very soon there would be no need for railways at all. They were so struck by the convenience of the motor-car as a form of transport, because it took its passengers 'from door to door', that they overlooked the many advantages of a railway.

First of all there is economy. When large quantities of goods or a great number of passengers have to be moved, railways can carry them at a price lower than that of road transport, because the use of

rails reduces the resistance to be overcome and therefore, weight for weight, enables a greater speed to be maintained for the same power. The fundamental advantage of wheel on rail against wheel on road has not been lost. Then there is speed. Because the railways use well-guarded lines with elaborate systems of signalling, they are able to reach and, what is more important on long distances, maintain speeds which are quite impossible on the roads as we know them. These advantages have been emphatically demonstrated during the war when, in spite of prodigious road and air transport, campaigns were based on railways.

A third advantage is comfort. To make motor-cars efficient it is necessary to reduce weight. But weight on the railways, once the train is moving, is not of such great importance. In actual fact, whereas a ton weight must be sufficient for four or five passengers in a car, a railway often allows 2 tons for a single passenger. This weight is represented by such comforts as corridors, restaurant-cars, buffets, and, on our best trains to-day, cinemas, hairdressing saloons, and other 'luxuries'. Actually these luxuries simply make a traveller feel at home, and the more he feels at home the more comfortable he is. Very shortly other comforts may be added, such as two-way wireless, enabling him to be in constant touch with his home or office while travelling.

The competition of road transport was such, however, that the railways, which had virtually enjoyed a monopoly since they killed the stage-coach, were forced to make many improvements. This they did by increasing the natural advantages already enjoyed. Economy and speed, which we consider together, have been increased in a number of ways, of which two are most important: streamlining and increased efficiency in the locomotives, and the use of new motive powers such as electricity and oil.

Streamlining is now the rule on all express trains, not only in Britain but in almost every country in the world. Railway locomotive designers, learning from aeroplanes and racing-cars, suddenly woke up a few years ago to the fact that for a century they had been burning tons of coal on every journey to overcome the resistance of the air. The amount of fuel that is used for pulling the passengers is small. Most of it goes into overcoming air resistance and the inertia of the coaches. Streamlining is a technical matter, but quite simply we can say that the object is to reduce the resistance of the air to a minimum by allowing it to

flow past the moving object gently and to prevent the formation of a partial vacuum.

When a locomotive thrusts itself through still air at 60 m.p.h. the effect is exactly the same as if a 60-m p h. wind was blowing into its leading surface. You need little experience of gales to appreciate that the smaller the surface presented the easier it is to move forward, or to prevent yourself being blown backwards. One of the essentials of streamlining is to allow as small a surface as possible for the air to push upon. But equally important in retarding a moving vehicle are the side currents of air or turbulence set up. They are caused by wheels as well as projections such as lamps and even the spaces between coaches.

The streamlining engineer attempts to remove all these causes of current which would move in many different directions and have the final effect of retarding the train. He covers the space between coaches, so that the whole train looks like a continuous vehicle; he builds headlamps and other parts into the bodywork so that the sweeping lines shall be maintained, and he even provides air-conditioning, so that it is not necessary to open windows. This also has the more important effect of enabling passengers to enjoy perfectly controlled weather conditions without the possibility of draughts. The smoking-carriage of an air-conditioned train is no longer blue with smoke, the dust particles being removed as fast as they are formed.

No more interesting example of the beauty of science could be given than the appearance of the streamlined train. Much of the attraction for passengers that these trains exercise is due to the lines, copied from the fish, the eagle, and other creatures which developed the streamlined shape because this was the perfect form for rapid travelling through air or water. The last word on streamlining has not yet been written; no doubt forms will be still further improved, increasing speed and, by reducing the amount of fuel consumed, increasing economy of working. Streamlining does not really pay on trains that are to average less than about 50 m.p.h., because it is not until this speed is reached that air-resistance becomes such an important factor in relation to weight and normal friction.

Another way in which economy has been obtained is by getting more out of the steam. In a steam locomotive we turn the energy in coal into mechanical movement, using steam as a convenient

working fluid to carry the heat. Upon the amount of steam obtained from a ton of coal, and the proportion of energy in the steam represented by its heat turned into mechanical power, depends the efficiency of the steam-engine. The best engine does not approach theoretical perfection; steam has enjoyed its supremacy very largely because coal has been so cheap and easy to obtain. Parsons revolutionized transport on the water by showing marine engineers how they could convert more heat energy from their steam by means of a turbine.

Now, slowly, the same thing is happening on the railways. Steam is being used at higher pressures, made possible by the invention of metal alloys able to remain strong at high temperatures. By improved methods of burning, greater effective heat is being obtained from the same amount of coal. The giant steam-engines used for generating electricity extract nearly double the power from a ton of coal obtained in 1920. The improvement of efficiency in the steam-engine from every point of view will ensure it many years of life, while the fact that at an efficiency of about 30 per cent. it is still able to compete with other power plants is evidence of its value. Among the notable feats of streamlined trains may be mentioned the maximum speed of 125 m.p h. reached by the L.N.E R. locomotive *Mallard* in July 1938. This would be difficult to equal by direct-power plants, without electric locomotives, where the whole power of a central station is available.

Many of the new streamlined locomotives in other countries are driven by Diesel engines in place of steam-engines. This may be a convenient moment to consider this invention. The principle of the Diesel engine is the ignition of the mixture of fuel and air by the heat generated by the compression of the air alone. The usual cycle consists of air being drawn into the cylinder, which is compressed on the next stroke. At the end of the compression stroke fuel is injected into the cylinder in the form of a fine spray, when it is ignited by the heat caused by compression. The burning of the fuel causes rapid expansion, providing the working stroke, and in the next stroke the burned products are ejected.

The advantages of the Diesel engine are numerous, the most important being that combustion takes place at a fairly constant pressure because of the regulation of the fuel spray. There is no sudden rise to a peak pressure as with the Otto-cycle internal-combustion engine, the 'expansion' pressure being at least equal to

that of compression, generally between 500 and 600 pounds to the square inch. This makes the Diesel engine very efficient thermally and therefore economical to run. Economy is further helped by the use of cheaper fuels than is possible in the case of the petrol motor, where vaporization at varying temperatures is so essential Fairly heavy oils and even finely pulverized solid fuels can be employed. We may in the future run our engines on some coal-dust combination which at the present time we find it difficult to use.

The chief disadvantage of the Diesel in the past has been that, because of its relatively high pressures, it is often heavy for the power produced. For this reason in the past it has been mostly applied to land or marine engines, but it is admirably suited to locomotives where oil fuel is cheaper than coal fuel, and it has recently made great progress in lighter forms. There are now a considerable number of Diesel-engined heavy lorries, for which its possibilities are only beginning to be properly appreciated.

On locomotives the Diesel may be used to generate the electricity which actually performs the work. This is because electricity is such an easy form of energy to control, all that is required for starting, accelerating, and stopping being a series of switches or resistances. The locomotive generates its own electricity, the Diesel working at a more or less constant speed, control being exercised through the increase or decrease of electric current. On other designs hydraulic torque convertors or clutches have been used with success.

In Great Britain the most significant development of rail transport in the last twenty years has been the increasing use of electricity as a motive power. Electricity is generated in power stations and on most tracks is supplied by a third rail, one of the running rails serving as an 'earth'. An electric locomotive to utilize power supplied in this way is really very simple, being nothing more than a motor with simple controls. The advantages of this system are cleanliness, rapid acceleration and stopping, simplicity of control, and reduced weight by the avoidance of a ponderous locomotive.

Hitherto development has been confined to comparatively short distances, although journeys of seventy miles or more are now made by electric trains. The difficulty of main-line electrification is chiefly the considerable cost of laying new lines, building generating or sub-generating stations, and converting the rolling-stock.

In course of time we may realize some scientific method of turning coal as our power source into electricity at the pit and conveying the power to where it is desired, which may be on a train 400 miles away. Scientifically, it is wasteful to mine coal in, say, Newcastle, carry the coal to London, and then use it as fuel to provide energy for a train going back to Newcastle. It is possible to carry coals to that city in more ways than one.

Science has not yet found a way of making electricity economically available for small cars. Electricity is a very convenient form of power, but the present methods of storage are uneconomical, and the disadvantages of an attachment to a wire render this method unsatisfactory except in limited cases, such as that of the trolley-bus. An engine using electricity is extremely simple, and as all forms of energy are fairly readily converted into electricity, the discovery of a light and economical storage battery would probably result in a great increase of electrical vehicles on the road. Capacity storage has not yet been achieved on a commercial scale. Such an invention would revolutionize the whole industry of power.

CHAPTER XI

SCIENCE BUILDS SHIPS

At the end of the eighteenth century the sailor had only one scientific instrument to assist him in the difficult and dangerous business of navigating the world's seas. It was a magnetic compass. To-day half a hundred scientific devices make sea travel safer, more comfortable, and faster. The magnetic compass or its counterpart remains as the one instrument essential for a ship to find its way through miles of open water. But it is a very different compass. The principle is the same, that of a magnetized needle pointing towards the magnetic pole, but ingenious new methods of suspending the compass make it more accurate, and scientific surveys are constantly at work checking the position of the magnetic pole which changes from time to time.

In addition to a magnetic compass all larger ships carry a gyro-compass. A gyroscope has a tendency to maintain its plane of rotation as fixed in space, regardless of the movement of its surroundings. It also has a tendency to rotate at right angles to the axis of torque applied to it; in the case of the gyro-compass the torque is the rotation of the earth. It will be seen, therefore, that the gyroscope has the property of indicating a definite direction which is not subject to changing conditions, except that of the rotation of the earth. It does not point to the magnetic north but to the true North Pole. To make a gyroscope carry out this function of indicating the position of the axis of the earth, a heavy metal wheel supported on horizontal bearings inside a vertical ring is driven by an electric motor at about 5,000 revolutions a minute. The vertical ring is suspended from the centre of the compass card, and on the sides of the case are two containers joined by a pipe filled with mercury.

When this case tilts, the force of gravity sends mercury from one container to another so that gravity and the earth's rotation are made to indicate the north on the compass card. One of the great advances of the gyro-compass is that it automatically compensates itself and is quite unaffected by the roll of the ship or any other conditions.

The gyro-compass is now ingeniously made, not only to indicate the ship's course, but also to keep it on that course automatically.

Even when the wheel is in the hands of an experienced helmsman a ship follows a twisting course. As the ship moves from its true course the helmsman corrects it, but inevitably it has moved some distance before the correction is made. Over-correction may result in yet another correction having to be made with a consequent loss of time and fuel.

By connecting the gyro-compass to a repeating mechanism, which is actuated by the slightest deviation from the correct set course, the rudder can be controlled. Not so long ago the rudder was moved by man-power—the helmsman actually applied the necessary load. Many men would be required to move the rudder, which may weigh 70 tons, on a modern liner, and therefore auxiliary motors are employed. The movements of the helmsman merely set the motors to work. The repeater is electrically connected to the rudder motors so that when it closes a circuit the rudder is turned one way or another as required. Immediately the desired correction has been carried out and the ship is on its true course, the connexion is broken, when the rudder returns to central. Thus deviations are immediately corrected. Corrections are so rapid, indeed, that generally it can be said that they hardly occur, for as soon as the ship shows a tendency to move from its course the necessary connexion is made. This not only enables the captain to attend to other duties but relieves the helmsman of monotonous and tedious work.

The gyroscope is also used on modern liners for providing an 'artificial horizon'. In order to determine the position of a ship it is necessary to 'shoot the sun' or a star, that is, to take the angle it makes with the horizon. But the horizon itself is often invisible, and the artificial horizon provided by the gyroscope through its stabilizing properties provides a line against which to 'shoot' under any condition of weather.

Yet another use of the gyroscope on some ships is as a stabilizer. In this case a very large gyroscope is used, firmly secured to the framework of the ship, and its stabilizing property is used to correct any roll that may begin. Much of the rolling of a ship is due to 'amplification'; a small roll starts and becomes greater and greater. The gyro-stabilizer immediately damps out the first roll and thus prevents a larger one being set up, so that the angle of the ship to the vertical in the roughest weather is never more than a few degrees. The fact that the gyroscope has to be so heavy, its

exact size depending upon that of the ship, prevents its being used on the largest liners, but it was installed on the *Conte de Savoia* and other vessels with a vast increase in passenger comfort.

The gyroscope is only one of the many scientific instruments and devices that assist the captain of a modern liner. For instance, he has an automatic sounder. In the old days, when a ship was in shallow water a sailor had to swing a lead on the end of a line which indicated the depth of the water below. Apart from the clumsiness of this method, and the inevitable errors, there was the disadvantage of a considerable time-lag between the moment the lead was swung and the moment the depth could be shouted to the captain. The automatic sounding-machine uses velocity of sound in water as its measuring line. Below the water-line on one side of the hull is a transmitting instrument and on the other a receiver. The waves sent out by the transmitter strike the floor of the sea, are reflected, and are picked up by the hydrophone on the receiving side. The time that elapses between transmission and reception gives the depth of the water. In practice, no calculations are necessary, readings of depth being given continuously and automatically on the bridge by electrical connexions. This method of sounding is so accurate and fast that even a 'bump' a few feet high on the ocean floor is revealed. A sunken ship, for instance, would be shown on the soundings chart and, in fact, the position of the wreck of the *Lusitania* was found in this way.

The greatest single discovery contributing to safety at sea has been radio. It has not only enabled ships to keep in touch with each other and shore stations, to obtain accurate weather forecasts and thus prepare for difficult conditions or, in the event of trouble, to summon immediate help, but also to obtain very accurate time-signals upon which the calculation of longitude depends. Now, radar is providing an even greater service. It does not solve all the problems of navigation, but it adds very much to the safety of a ship in darkness or fog. Many vessels are already equipped with radar and in time it will probably be considered as standard a fitting as a compass.

There are two ways in which radar can be used by ships in peace-time. By an adaptation of the methods used for directing bombers to their targets in war, ships in any part of the world can be given their position with great accuracy from shore stations. These shore stations can cover a circle with a radius of about

1,500 miles, so that only comparatively few are required to control all the chief ocean routes. It is not necessary for the ship itself to have elaborate radar equipment. A cheap and almost automatic device will be sufficient for a ship to be given its position at any time of the day or night with great accuracy.

The other manner in which radar will be used is by installing the 'Plan Position Indicator' (P.P.I.) sets specially designed for the use of the merchant navy. Using one of these instruments, the navigator has a 'plan picture' of everything within a radius of about fifteen miles and he is then able to navigate in narrow waters under conditions which, normally, would make it unsafe to proceed at all. Even a small buoy shows up clearly on the P.P.I. screen. In fact, by fitting buoys with corner reflectors, which are simply mirrors for radar pulses, buoys can be made to give particularly strong reflections. The navigator sees the outline of the coast, piers, other ships, and obstructions of every kind. By using a special chart and projecting the P.P.I. image on to it, he can fit the picture of what is there into that of what ought to be there and see his own ship, indicated by a circle of light in the centre, proceeding along its course.

There are one or two difficulties that prevent this being the 'perfect' navigation aid. The circle of light in the centre represents the area over which the radar pulses are reflected so quickly and strongly that the set is 'paralysed'. In the normal outfit this would be a circle of about 200 yards in radius; nothing within this circle would show on the screen because of the 'paralysis'. To some degree this handicap has been overcome by designing sets which can be 'tuned' to reduce the circle of paralysis to 50 yards. This means a decrease in over-all sensitivity, so that the operator can use it only for brief intervals, in case he misses a more distant obstacle.

The other difficulty is that until every ship is compulsorily fitted with radar, the navigator may know he can 'see' a ship approaching him, but must remain in doubt whether it can see him and therefore has to act with great caution, obeying the normal rules of the sea to avoid collision. The danger that the set may not be working properly and may therefore be giving a false picture is avoided by incorporating an automatic indicator which immediately gives warning if performance is less than perfect.

In spite of these handicaps and others, such as that P.P.I. sets

cannot be worked continuously for more than a few hours, radar is of immense assistance at sea. It means that instead of waiting for hours or days outside a fogbound port, a ship can proceed to its anchorage when visibility is nil. Navigation can also be aided by the use of infra-red telescopes, developed during the war for the use of night snipers. In this device the infra-red light from a searchlight reflected by the 'target' is picked up by the telescope. The infra-red light image is invisible to the human eye, but is made visible by turning it into an electron picture on a cathode-ray tube screen.

There are many dangers at sea and in the past thousands of lives have been lost as the result of fire and shipwreck. Scientists have devised many ways of eliminating, or at least reducing, these dangers. Such boats as the *Queen Mary*, for example, deal with fire by a special installation making use of the electric eye. Any smoke passing through the air-ducts in all parts of the ship is immediately detected. If the fire should occur in the cargo-holds it would be immediately extinguished by carbon-dioxide gas released from steel cylinders.

Then again, suppose that the passengers, through some mishap, have had to take to the boats These are no longer comparatively small and frail oar-propelled boats but motor-driven. Some are even large enough to be radio equipped, although an ingenious gear makes it possible for them to be launched by one man. No longer can half the lifeboats be rendered useless owing to the sinking ship's list. Modern lifeboats are equipped with slides which enable them to be lowered smoothly down the ship's side, even when the list amounts to as much as 70 degrees.

During the war a very great deal of research was carried out into every aspect of life-saving at sea. Much new equipment, from special clothing to minimize the danger from exposure, to apparatus for making salt water fit for drinking, was designed and manufactured. Not only has science very greatly reduced the hazards of what was a dangerous trade, but it has also increased the chances of survival if, in spite of all, an accident takes place. Eighty years ago it was not unknown for a hundred ships to be sunk in a month; and that was in peace and not in war. To-day, the enormously reduced risks of travel at sea are reflected in the insurance rates on passengers and cargoes which are now almost trifling.

When speeds of over 20 knots are considered for large vessels,

an enormous rise in the power required is necessary for every small increase of speed. Much more attention has therefore been paid by scientists to the design of the shape of ships, for the less power wasted in pushing aside the water, the more is available for driving the ship forward. The alteration of the breadth of a ship at a certain point by a few inches may save thousands of tons of fuel during its lifetime.

Streamlining, so important in the case of trains and motor-cars, has a double application to ships There is first of all streamlining for water, and then streamlining for wind resistance. At speeds under 60 m.p h air resistance is not of much importance, but it must be remembered that a ship may have to drive into a 40-m.p h. wind at 20 m.p.h., the relative speed in this case being 60 m.p.h. Scientists have therefore recently applied the principles of streamlining to ships' superstructures and made possible a great saving of power, which can be used either in saving fuel or increasing the speed for a given amount of energy.

Water is much more ponderable than air, so that streamlining under the water is very important, even at low speeds To determine the best shape for a vessel, as well as to discover how it will behave in various conditions, a tank is now used through which a model can be towed under controlled conditions. This is equivalent to the wind-tunnel for aeroplanes. The model of the proposed boat, made exactly to scale, is fixed to a towing carriage which straddles over the tank and carries various delicate instruments for measuring the pressure of water and other factors. The carriage is moved at various speeds and the effect of the water on the model carefully measured. Conditions similar to those in a storm at sea can be produced in the tank. As a result of tests made in this way, the design of a ship may be modified, and the new model tested again until a completely satisfactory result is achieved.

These are only a few of the services that science has rendered to the shipbuilding industry. We might mention welding which, by eliminating rivets, saves a great deal of weight in steel boats. The saving in weight may amount to a thousand tons, which can be devoted to more useful purposes. Welded ships are only possible because welding has been scientifically investigated and the strength and safety of welds greatly increased as a result of physical and metallurgical research.

Shipbuilding is now a highly scientific industry. In the near

future we shall probably see the increasing use of light metals in liners. The new *Mauretania* was the first ship to have aluminium funnels. In a big liner the total weight of the structure may be 60,000 or 70,000 tons, while that of the passengers and luggage is, perhaps, only 1,000 tons, so the importance of saving weight in the structure itself can be appreciated If ships the size of the *Queen Elizabeth* could be built of light metals, a saving of 20,000 or 30,000 tons might be possible, with a corresponding reduction in the amount of fuel used or a great increase in speed. Recent technical experiments suggest that with the part adoption of the 'skimming' principle and the use of various new alloys, sea travel may be speeded up to a degree hitherto considered quite unattainable.

CHAPTER XII

AVIATION

FLYING has become a great industry; it is founded and depends entirely upon scientific methods or upon principles developed by scientific research. It was not until men ceased to build aircraft on the 'hit-or-miss' principle and began to study the new aeronautics that any real progress was made. Until the end of the nineteenth century, flying pioneers had scarcely really understood what they were trying to do. If they had considered the mechanics of flight at all they would have realized why their flapping-wing machines, or 'ornithopters', were doomed to failure before they were made.

When they forgot about motive power for the moment and experimented with gliders to discover what really happened when a flat surface moved through the air, they began to grasp the meaning of aeronautical engineering. It is worth noting that it was not until almost twenty years after the first heavier-than-air flight that gliders really developed and journeys of a hundred miles or more in a flying machine without an engine became possible. The pioneers who watched birds in the hope of discovering the secret of flight were so impressed by the screw-like flapping of wings that they did not appreciate the significance of the almost effortless soaring flight of the eagle or sea-gull as it makes use of the upward currents of air. Yet it is strange that gliders were first suggested, not recently, but several centuries ago by Roger Bacon, whose early experiments were continued by Lilienthal.

Heavier-than-air flying was really impossible until the internal-combustion engine reached a reasonable degree of efficiency. The steam-engine, used with some success by Sir Hiram Maxim, required too much weight for each horse-power it produced, although the great improvement in steam-engine efficiency, coupled with the lifting power of modern aeroplanes, has made this power more practicable to-day. The aeroplane was also impossible until the propeller or air-screw had been invented, and it is interesting to remember that until a hundred years ago people had not thought of propulsion by the screw-propeller in any form. The earliest airships, like the sea-ships of their time, were propelled, or rather designed to be propelled, by paddle-wheels or oars. The air is not sufficiently dense to make this method practicable.

Scientists have greatly improved the propeller ever since the invention of heavier-than-air flying. The propeller is really a section of a screw, the blades representing part of the thread. For propulsion purposes this thread is vastly exaggerated, but nevertheless every propeller can be defined in terms of the number of turns to the foot made by the thread, or the 'pitch'. For each engine and aeroplane there is a number of revolutions at which a given propeller exercises its maximum pull. This varies, of course, with the height of the plane, since the air becomes less dense as we ascend. It is a great advantage, therefore, to be able to vary the pitch of the air-screw, and if we had an infinitely variable air-screw we should have the equivalent of a gearless car. Scientists have devised variable air-screws which have made flying safer and more economical. A variable air-screw is really essential to high flying, because the screw that will 'grip' efficiently at ground-level when the aeroplane is taking off will not prove efficient at an altitude of 10,000 feet.

The most important change that has been made to aeroplane engines is to increase their efficiency compared to their weight. There was no reason why the pioneers should not have had 500-h.p. engines for their aeroplanes, except that a 500-h.p. engine would have weighed so much that a vast wing-span would have been required for lifting. To-day, the power weight ratio, as it is called, is being reduced every year. This is being accomplished in various ways. The most obvious is the use of lighter metals, as strong and as hard-wearing as those weighing far more which were formerly used The metallurgist has rendered tremendous services to aviation by producing alloys of aluminium and magnesium of great strength, hardness, and wearing qualities. Incidentally, the advances made with aeroplane engines have been of great value to various forms of ground transport.

Another way in which the power. weight ratio can be increased is by improving the thermal and volumetric efficiency of the engine. This has been done through technical improvements in design, and also by the inclusion of superchargers. The blower or supercharger is really a little auxiliary pump which compresses the air before forcing it into the cylinders It is used on most racing cars and on many aeroplanes. It is essential for high-flying aeroplanes in order to increase the amount of oxygen taken in at each 'suck' in regions where the air is thin. If a supercharger is not used the

volume of air taken in remains the same, but the weight of oxygen in it is diminished, and the result is incomplete combustion or a sensible loss of power at low compression values.

For various technical reasons it was apparent some years ago that the practical limit to the development of the present internal-combustion engine for flying was being approached. Whatever improvements were incorporated, the inherent technical limitations of the engine made it almost impossible to improve performance beyond a certain point. If greater speeds were to be attained a completely new principle of propulsion would need to be evolved. The new method was, rather obviously, that of the gas turbine. The principle of propulsion by 'reaction' is old, but the development of practical engines, capable of giving reasonable safety, fuel consumption, and ease of control, is extremely difficult. The main idea of the 'jet engine' goes back to the dawn of mechanical engineering, but its practical adaptation to aviation is scarcely ten years old, and many of those ten years have been devoted to war which, while it gives the advantage of intense research in branches of science likely to be of military value, delays all normal civilian experiment.

We must distinguish between the 'jet plane' and the 'gas turbine'. A jet plane may have a gas turbine to supply the 'jet' which drives it, but a gas turbine can be harnessed to various purposes from driving a dynamo to driving a propeller. There seems likely to be an intermediary period during which some aircraft will continue to have propellers, but be driven by gas turbines rather than internal-combustion engines. Eventually, however, it is almost certain that the 'jet' will become the universal method of propulsion in the air.

In the jet plane a stream of rapidly expanding gas is driven from the rear of the plane, through a comparatively narrow orifice, at a high speed. In accordance with Newton's third law of motion, the plane is driven forward in 'reaction' to the stream of gas going backwards. It is a popular misconception that the jet 'pushes against the air'. The reaction takes place equally well in a vacuum. It is purely 'reaction', and a jet-driven plane, other things being equal, is more efficient in the stratosphere where there is little air than at lower levels where the air resistance is considerable. A plane driven by an airscrew, on the other hand, is less efficient at great heights because there is so little air for it to 'pull itself along'.

The advantages of the jet method of propulsion are many and

can only be briefly summarized. The fact that there is no need for a propeller means that the reason for the undercarriage disappears. The undercarriage is necessary to keep the airscrew blades off the ground when the plane is taxi-ing or at rest. The jet plane can land 'on its belly' with all the additional convenience involved. The engine and method of propulsion lend themselves to designs which are excellent for streamlining and for giving a clear field of view. The 'direct drive' of the engine means that there is a minimum of moving parts. This helps to eliminate waste from friction and means that more of the engine power is devoted to driving the plane through the air. It also gives the advantage of freedom from vibration or noise and therefore simplifies airframe construction with resulting greater comfort and reduced risk of mechanical breakdown. The jet plane has not the inherent limitations of the internal-combustion engine craft and it is therefore possible to contemplate great increases in maximum speeds. Add to this that the jet engine is capable of burning comparatively cheap fuels instead of the high-quality aviation spirit demanded by the normal engine, and some of the reasons that will make this method of propulsion supreme can be appreciated.

In the jet engine air is scooped up by the forward movement of the plane, compressed, and fed to a combustion chamber into which the fuel is also fed. The fuel burns and the resulting gases, rapidly expanding because of the heat, are forced to escape through one or more orifices to produce the 'jet' which forces the plane forward. On their way to the orifices the gases pass turbine blades which work the compressor. That is the principle of the jet plane, in which great progress has been made in the last six years. Many further refinements are coming. It is clear that the power of a jet engine cannot strictly be measured by horse-power but must be rated by 'thrust'. The weight per pound of thrust of jet engines has been halved in recent years and will be reduced still further. At the moment the handicap is high fuel consumption, meaning a comparatively short cruising range at high speeds, but research is showing how this source of inefficiency can be reduced.

With the perfection of the jet engine, the speed record may be expected to creep up to 700 m p h., 800 m.p.h., and then to 1,000 m.p.h. Crossings of the Atlantic in two or three hours should become commonplace. But before this becomes possible we have to pass through the danger spot of the air, the threshold of sound-

speed. When the speed of an aircraft begins to approach the velocity of sound extremely violent turbulence is set up, so that the plane is in danger of being torn to pieces. The problem of thrusting through this danger zone on the threshold of sound is a difficult one and may prove more troublesome than the designing of power units capable of driving an aircraft at such speeds Once this velocity is passed some of the turbulence disappears. The problem is likely to be solved by a radical change in the design of aircraft. Instead of the orthodox wings, fuselage, and tail-plane structures we have known since the first days of heavier-than-air flight, research is likely to show that at speeds on the threshold of sound the 'flying-wing' design avoids the worse effects and we may eventually come to the aircraft which has folding subsidiary wings, used only for the comparatively low speeds required for take-off and landing.

With high speeds and stratosphere travel will come the sealed cabin, where the pressure is artificially regulated and the temperature is constant, even when the plane is travelling in the ice regions 30,000 or more feet above the earth. Pressure cabins, with superchargers supplying fresh air, have had considerable 'teething troubles', but experiment and research will overcome these disadvantages.

During the war the helicopter was brought to a practical stage. It was with helicopters, using horizontal propellers to rise and fall, that the pioneers of heavier-than-air flight experimented. They had no success, and nearly all attempts at building helicopters were practical failures until the arrival of the de Cierva autogyro showed how true helicopters could be adapted. In this machine the horizontal blades are not motor-driven but are propelled by the forward motion of the plane. They are not, in fact, propellers at all, but moving wing surfaces. The moving-wing plane, as distinct from the orthodox fixed wing, enjoyed some success. It is not capable of much vertical movement or of remaining stationary in the air, but attained near to this ideal with a forward landing-speed of only a few miles an hour. The modern helicopter, developed as the result of the work of Sikorsky, has a large flexible rotor turned by its motor. It has no vertical air-screw, but is driven forward, or backwards, by the movement of the horizontal rotor. It is capable of remaining stationary in the air, and at demonstrations passengers have climbed aboard a helicopter, hovering a few feet above the

ground, by rope ladder. It has also been possible to change the tyre on a landing-wheel while the plane 'jacks itself up' to three or four feet above the ground, remaining perfectly still relative to the earth.

The advantages of the helicopter are numerous. It can, theoretically, land on a garden lawn or a city office roof. It is possible to reduce speed so that navigation can be carried out by dropping down to look at a signpost. It should be 'foolproof', for a 'stall' in the accepted sense is not possible. If the engine gives out the rotor continues to revolve and sustain the aircraft under pressure of the air upon the blades. The speed of revolution is slowly diminished, but the helicopter comes gradually to rest in a safe landing.

In practice, the helicopter continues to have certain inherent disadvantages, such as relatively low speed and rather complex controls. Because of the low speed it is not likely to oust the fixed-wing aircraft on long-distance passenger services, but as a 'taxi' or a 'feeder' it may prove invaluable, as well as having certain special military and police uses. The slow speed enables it to be used for regulating traffic, for carrying out searches, for crop spraying, and for other special purposes.

CHAPTER XIII

SCIENCE LETS US TALK

COMMUNICATION at a distance is one of the greatest contributions of science to civilization, and to-day it is a major industry. The importance of this work is not limited to the pleasure and convenience that easy and rapid communication gives us. Modern industry would find it difficult to exist without the cheap and rapid means of conveying information which enable supplies to be co-ordinated, prices adjusted, and trade to continue. It is certainly very convenient for us to be able to telephone a friend in the country that we are coming in for tea, or to speak to a relative 3,000 miles away about personal matters, but trade and business connexions are far more important.

Telegraphy and telephony were developed largely for these purposes, but they have had another effect which perhaps is not fully realized. By making it easy and cheap for the people of different countries to communicate with each other, the possibilities of misunderstanding should be reduced. Instead of the three or four weeks which used to elapse before news could be brought from places a few thousand miles away, it is transmitted instantly. People in Australia can hear Big Ben a fraction of a second before people living half a mile away from the clock, unless they too listen by radio. It is possible for a single man to address 100 or even 200 million people simultaneously, a thing which was inconceivable only thirty years ago. When to this is added the opportunity for this number of people to see something simultaneously, the effects will be far-reaching.

Communications should have the effect of drawing the different peoples of the world together, of making them realize the truth that in the scale of time they are not fundamentally different from each other, and that the points they have in common enormously outweigh those on which they disagree. The fact that at present the great blessing of easy and rapid communication is only too often used as a means of political propaganda and to stir up hatred should not discourage us, for in the end it will prove a greater power for good than evil.

The British Empire, as it is at present organized, could not exist without its communications, enabling the heads of different

countries to consult with each other immediately and to avoid the many misunderstandings which were so common when information took weeks to travel from America to England. It is quite possible that we should never have quarrelled with our American colonies if there had been transatlantic telephony and telegraphy in the eighteenth century. These inventions of the nineteenth century, perfected in the twentieth century, may yet be the means of drawing the two countries together again.

Telegraphy, the first of the modern methods of communication, represented an enormous step forward. For 3,000 years before the invention of telegraphy the speed of signalling had not appreciably increased, and signals were limited to the crudest messages. The elaborate semaphore systems which were developed early in the nineteenth century, just before the birth of telegraphy, were not fundamentally different from smoke signals used by primitive men. The great advantages of telegraphy were that, first of all, the speed at which the signal was transmitted was limited only to that of electricity, enabling a message to be sent seven times round the earth in a second. Secondly, that the distance which the signal could be transmitted was not limited by the range of the human eye or by the curvature of the earth. Any visual form of signalling is confined to a distance of a few miles under the most favourable conditions and requires relays with human intervention. Actually, arrangements were made for a semaphore from the south coast to London, but there had to be relaying stations at short intervals, men at these points working their semaphore arms in accordance with the movements of the preceding station, which they read through a telescope.

Telegraphy is a means of communication based on the detection of an electric current in a circuit. The most complicated modern apparatus depends on this principle, although the means of detecting the presence or absence of electricity has changed considerably. The first method devised by Morse was to have a pencil moved by an electro-magnet, so that when the current was present it wrote on a strip of moving paper, and when it was off allowed the paper to move unmarked. The result was that in response to a series of long and short signals, the pencil would write a corresponding series of long and short lines, the familiar dots and dashes.

Other similar devices were used, notably an inked wheel and a

stylus which marked the paper. The first real change came when it was found that the sounds made by a lever striking the stops as it was moved by the current could be interpreted as dots or dashes according to the interval between the sounds, and for a considerable time most telegraphy was read in this way. To-day the tendency is back to greatly improved forms of automatic receiving apparatus. The 'ticker' which you see in clubs and business houses actually prints the message. This is done by using a series of code impulses instead of the Morse signals. Five impulses can be so varied as to give thirty-one different signals, making the little inked wheel which carries the letters of the alphabet turn to one of twenty-six different angles before pressing against the moving paper. The other signals are used for spaces, paragraphs, &c. In the great telegraphy offices the principle used is generally that of a perforated tape. The signals actuate a mechanism which cuts holes in response to a code, and these holes in the perforated tape in turn work, by levers or electric contact, a printing mechanism. A great number of messages are still received and transmitted manually, but the greater amount of commercial work is carried out automatically.

At the transmitting end the greatest improvements have been the introduction of automatic apparatus working on the same principles as the receiver, but in reverse, and the introduction of multiplex systems enabling many messages to be transmitted simultaneously on one line. The first duplex systems were based on making the transmitter sensitive only to its own signals and not to those coming the other way. Then was introduced the duplex system with double currents, giving four messages simultaneously, two each way. Now, by more elaborate apparatus, it is possible to transmit a large number of messages on different frequencies. The principle is the same as in wireless, where you have a number of broadcasting stations transmitting simultaneously on different wave-lengths without interfering with each other. Filters at the receiving end ensure that only the desired frequency is received by each piece of receiving apparatus.

Electric signals, like visual messages, require relaying. The current 'dies out' after about 200 miles in the normal circuit and the signal becomes feeble. Relays work quite automatically, the signal, instead of being received, simply varying the current in a new circuit with its own local source of electricity. To-day relays

not only send on the signal with new strength, but actually improve its clarity. During transmission over considerable distances there is always a certain amount of interference from natural or man-made causes, and the relay, by selecting only the best part of the signal, cleans it up, as it were, before sending it on.

A comparatively new use of telegraphy is the transmission of a large number of pictures by wire. Experimentally, facsimile writing was transmitted by wire many years ago, the principle being the simple one of two pens connected to electro-magnets through rheostats or variable resistances which made the angle of the pens' movement vary in accordance with the strength of the current received. The modern method of transmitting a picture is much faster and less crude. The photograph is first 'broken down' into a series of dots of varying light and shade by being scanned by a light working in conjunction with a photo-electric cell. The cell varies the current in accordance with the amount of light reflected, and at the receiving end the reverse process takes place. The incoming current is made to vary the intensity of a light on a piece of sensitive photographic paper which is afterwards developed to give an exact reproduction of the little dots. This is like slow television with wires and without the added complication of movement.

As in all telegraphic work, the very feeble electric currents which are the actual signals are used merely to control apparatus which derives its power from local sources. The signal is amplified or 'boosted', the original electric current after travelling several hundred miles being far too feeble to work anything but the most sensitive receiver.

Neither wireless not telephony has ousted the telegraph, which has certain advantages of its own, notably cheapness, owing to the many hundreds of words a minute that can be transmitted over a single line, and secrecy, by the use of codes. There are many thousands of ocean cables in the world, and they will be an essential link in our communications for many years to come. The speed and quality of transmission and reception is constantly being improved by research work. To give one example, there was perfected a few years ago a plough which actually lays a cable in the bed of the ocean, safe from breakage by the trawls of fishing-boats or other obstructions.

An advantage of telegraphy is that the message is permanently

recorded. The advantage of telephony is that you actually hear your correspondent and can hold rapid conversation with him. The meaning of words varies with the way they are said, and the telephone enables you to catch these shades of meaning. There is also the great advantage that the apparatus can be installed in any house and requires no technical knowledge to use. Telephony depends upon everyone with whom you might want to communicate having the necessary receiving apparatus. Whereas you can telegraph to almost any address in the world, you can still telephone only to a limited number of people. Mass production of instruments, improvements in long-distance telephony by more delicate apparatus and improved methods of 'boosting', and the introduction of better speaking and receiving apparatus on the microphone principle are making the telephone a more valuable means of communication every year.

By using apparatus for recording, the disadvantage of impermanence for important conversations can be overcome. It is no longer essential to say 'I will confirm that by letter'. The recording apparatus, which is on the same principle as that used for dictating machines, but with electrical impulses taking the place of acoustical movement, puts the conversation on to a cylinder. This cylinder can afterwards be 'played back', or the speech typewritten from it at any desired speed. At a modern business conference on the telephone, four men can take part and, a little later, be presented with typewritten copies of everything each one said.

The greatest change in the telephone in the last few years has been the wide introduction of automatic apparatus, with its advantages of labour-saving and quick connexion. In non-automatic exchanges, when you ask a telephone operator for a number she has to select the connexion you require from some hundreds in front of her, or, if you require another exchange, connect you with one of the lines going to that exchange. By a process of selection you are eventually switched through to the required number. This may entail making a number of different connexions by hand, and the speed with which you are connected, even though a minute or two may seem a long time when you are waiting, is a remarkable testimony to the skill of the operators.

In the automatic telephone, of which the working puzzles so many people, the method is the same, except that it is all done by

machinery. If a description sounds simple, it is because the principle is simple. But the apparatus is ingenious and delicate, as a visit to an automatic exchange will convince you. Probably you will be bewildered by the thousands of switches and little arms all moving as if by magic. We are naturally impressed and sometimes confused by numbers. If you saw an automatic exchange which had only ten subscribers, you would follow it fairly easily. An exchange with 10,000 subscribers is simply this exchange multiplied a thousand times.

The dial on your telephone is in fact a little transmitter, the signals sent out being electrical impulses which vary according to the distance the dial is turned, that is, with the letter- or number-hole in which you put your finger. When you lift the receiver, a spring switch immediately connects with the exchange and the line is 'live'. You dial, perhaps, the letter D, and the impulses go to a bank of switches all of which can connect you with any exchange beginning with the letter D. Next you dial, say, A and your signal is narrowed down, being connected with switches which enable you to reach any exchange beginning with DA. The final letter signal of, say, B connects you through to the DAB exchange, and now begins the process of selecting the number you require in this particular exchange.

This is carried out on the same principle by selectors Your first signal of, say, 8 connects you to a bank of switches which can give you a connexion to any number in the 8000's. Your second signal of 3 selects switches connecting you with any of the 8300's. Your third signal of, say, 7 connects you with the 8370's, and your last selects one of the ten in this group.

Really it comes down to this, that with the automatic telephone you telegraph for your number, using a simple code and transmitting your message instead of handing it to an operator. One of the triumphs of science in industry is the way in which it has been able to make exceedingly technical operations so easy that a child can perform them. Described like this it sounds simple, perhaps, but the selectors are ingenious switches in which arms travel up and down in accordance with the signals received, making contact with any one of ten points.

There are further refinements, which automatically book the cost of the call to the subscriber making it, and enable automatic exchanges to be worked in conjunction with those of the manual

type. One day the spoken word may be printed direct to paper. Portable telephones, by the aid of radio, will keep us in touch with our friends as we travel, and perhaps we shall see them at the same time. The science of communication, the annihilation of time and distance, has speeded up and expanded every industry in a fashion that would have seemed unbelievable only a few years ago.

CHAPTER XIV

SCIENCE CONQUERS THE ETHER

WHEN we look at a red-coloured object what actually happens is that light-waves of the particular length which produce the sensation of redness on the sensitive nerves in our eyes are reflected by the object. Our eyes are sensitive receiving sets for vibrations in the ether, able to detect many different wave-lengths and to interpret them by the sensations we call colours. But the wave-lengths we can detect must be within a certain limit, what we call the visible spectrum. To waves outside this band our eyes are not sensitive, although other parts of our body may be, just as our skin is sensitive to ultra-violet rays.

In addition to the wave-lengths which produce these sensations of light and colour and heat, there are in the ether, that mysterious all-pervading 'nothingness' which we postulate, many other waves. We can, indeed, suppose that there are an infinite number of possible different wave-lengths. At present science only uses those within certain well-defined bands, the best known of which are the waves we use for broadcasting. We use the waves as a convenient medium for carrying signals which can be interpreted as sounds, but theoretically there is no reason why other waves should not serve the purpose. We could construct an instrument to flash a succession of different coloured lights which would be received and turned into sounds, or we could use heat rays or ultra-violet rays for broadcasting. Science selected the wave-lengths used because they are the most convenient, travelling long distances with less interference and loss of strength than shorter or longer waves.

The science of wireless or broadcasting consists in turning sounds into ripples in the ether, and then receiving these ripples and turning them back into sounds that correspond with those at the transmitting end. Note the word 'correspond'. It is not the actual sounds that are transmitted. Whereas at the transmitting end there may be an orchestra of fifty instruments each producing its own sounds in its own way, at the receiving end there is only a single piece of material to vibrate the air and produce waves which have the same effect on our ears as those of the full orchestra.

All the transformers, valves, condensers, and tuning-coils sim-

ply aid this transference of sensations from one place to another. The designer of a wireless set has behind him the research of hundreds of scientists for fifty years or more, and he is now concerned not so much with the technical problems of turning the sounds into electrical impulses, which is the function of the microphone, and then into ether vibrations, which is the function of the transmitter, as in ensuring that the wave-length is constant. Also it is essential that the receiving apparatus should be able to select just the wave-length it requires and no others, so that it avoids 'interference', while the sounds reproduced must resemble those at the transmitting end as accurately as possible. It should be observed that the signals are sent simply as impulses on a given wave-length. Whereas with sounds each wave-length produces its own sensation or sound, with wireless the same wave-length is used and the different signals are produced by varying its nature.

It is not possible, in brief, even to outline the part that science has played in building up the great industry of wireless. The industry is entirely technical, and because the controls of a modern wireless set are so simple that a child can manipulate them, it would be a mistake to suppose that the apparatus itself is anything but complicated. It controls electrons travelling at speeds of millions of miles a second, and deals with minute electrical currents necessitating the most exact measurements which could not have been made even under laboratory conditions only a few years ago.

The great triumph of science in the wireless world is the extraordinary simplicity of control which it has been able to achieve. You ask for a valve with a certain code number, slip it into your set, and you have under your control amazing forces about which the greatest men of a century past had not dreamt. Science has provided all kinds of devices for simplifying control. For instance, it is no longer necessary to listen to know whether your set is perfectly in tune, that is, exactly on the desired wave-length. A small tube, of which you see the end as a little green light, measures the output and tells you when it is at a maximum. Perhaps this will become automatic before long. It is not necessary to turn a knob moving a condenser to the correct position in order to tune to a desired wave-length. You press a button, and in response an electric motor moves the condenser until it reaches the right point.

Broadcasting would be useless if receiving sets were not cheap.

The reduction in price of sets, so that you can buy for fifteen pounds a better set than you could have obtained for a hundred pounds twenty years ago, is a triumph of science and automatic production in industry. The manufacture of the various parts has been made almost entirely automatic, and has been simplified to the point where a valve, for example, an exceedingly delicate and complicated piece of apparatus, can be manufactured by girls with no technical knowledge at all. Ingenious instruments test the components and the set at every stage, carrying out trials in a few minutes which twenty years ago would have taken an experienced wireless engineer many hours.

Up to the present the chief use that has been made of the ether is to transmit signals that can be interpreted as speech or music. Of course, those signals can be converted in any other way we desire by means of suitable apparatus. Instead of turning the impulses in the ether into impulses of sound, we can turn them into waves on water, or make them produce colours. Television is in fact the transmission and interpretation of ether signals to form patterns of light or pictures. A use of these ether signals which may become very valuable, although somewhat in the experimental stage at the present moment, is that of controlling various mechanisms. If, after the detection and amplification of the signals, instead of converting them into sounds we use them to work electro-magnets, we have a simple means of controlling an apparatus without any connecting wires. The only connexion is an invisible and completely flexible 'bridge' in the ether. This radio control was used during the war for aiming bombs and rockets, but it is handicapped for military purposes because of the ease with which the controlling signals can be interfered with by the defence.

When describing the automatic telephone it was explained how a simple dial transmits a number of different signals by means of a code of impulses. With just ten different types of signals combined in various ways it is possible to produce thousands of different combinations of impulses, sufficient to give the million or so subscribers in the London telephone area each a separate 'impulse code number'. If at the receiving end of a wireless circuit we had apparatus similar to an automatic telephone exchange, we could transmit any one of these millions of signals, and by opening or closing switches set in motion or stop an infinite variety of machines.

This is what is meant by wireless control, and it must be shown clearly what is the difference between this operation and the transmission of power by wireless. The amount of current that needs to be transmitted to work a wireless receiving set for interpretation into sight, sound, or controlling signals is very, very small—hardly sufficient to move a fly's wings, and not nearly enough to light the valve which derives its current from a low-tension battery Only a very minute part of the output of the transmitting aerial of a powerful station is caught by your aerial, and the fact that this can be made to produce sounds is due to the high-tension power supply to your loud-speaker The power for working the set is provided locally, by batteries or the mains, and all the wireless signals do is to control this power, varying it in accordance with the transmission

In the transmission of power, light, or any other form of energy by wireless the actual energy is transmitted To light a room, all that would be required would be some form of receiver, without batteries or mains, and a lamp. This is not yet practical. Scientists have succeeded in transmitting a little power a few feet, but the loss of energy in transmission is so great that it is still more economical and practical to use a wire to carry the current

In wireless control the signal received need be no stronger than that required for the reception of sound Instead of being passed to a loud-speaker, the signal is made to control an electro-magnet which opens or closes a switch. The power to open the switch is produced locally, as also the power to work any machinery set in motion as the result of the workings of the switch.

In a wireless-controlled steamship, for example, the signals open and close the throttle, increasing or decreasing the speed, move the rudder, and perform other actions. But it is necessary that the ship should have some other means of generating its own power to perform the actual movements in response to the control. The wireless does no more than the captain when he moves his telegraph to 'Full Speed Ahead' or shouts an order to the man at the helm. Indeed, it is perfectly possible to have control by a shout, and possibly you have seen the ingenious model motor-cars that stop when a word is shouted In this case the sound-waves actuate a controlling mechanism. In others a light signal may operate a photo-electric cell.

Possible uses for wireless control in industry that occur

immediately are the direction of big undertakings from a distance, particularly where they have to be situated in remote places under unpleasant conditions. It would be fairly simple to devise apparatus that would open and close the sluice-gates of a dam in response to wireless signals sent from many miles away Moreover, it would be possible for a transmitter at the dam automatically to send messages indicating, let us say, the height of the water

Closely allied to this subject is that of the so-called death-ray No doubt you have heard rumours of rays that will bring down aeroplanes or strike men dead. But no such rays exist at the moment for one vital link is missing—the receiver in the aeroplane or on the man No one is likely to install a receiver to receive signals which are to do him harm, indeed, men are likely to do the opposite and screen their engines in such a way that they cannot be affected by comparatively powerful signals The death-ray implies the ability to transmit power, and, moreover, implies an ability to direct signals in a way which has not yet been mastered Fortunately, it is likely to be some time before these rays are achieved, and it is then more probable that the discovery will be used for such purposes as transmitting useful energy by wireless or for directing signals along a narrow path instead of distributing them as at present.

The great step in radio which is likely to affect the average man in the near future is television, or the interpretation of wireless signals into light and shade The modern television set is so simple that any one with no technical knowledge at all can work it, which means not only that television has been greatly simplified, but that science has been applied to such good purpose that reception has been made almost automatic. As with many other things, science has been applied to simplifying control for those without technical skill The early photographers had to make their plates as they went, and then expose them in a camera which called for considerable knowledge to use it at all Now, anyone who can look in a view-finder and press a lever can take successful pictures. The same process is taking place with television, control being as far as possible entirely automatic.

What are the scientific principles of television? Whereas in sound broadcasting the problem is to turn sound into ether waves and transmit it to a receiver which will turn the signals back into sounds, in television we turn the impressions of light in our eyes

into ether waves, and then turn them back again into light or shade It is a vastly more complicated affair, because our eyes are very much more sensitive than our ears Moreover, movements in the light and shade of the picture which we are watching introduce a great complication, for we have to transmit a continually changing picture Fortunately, electrons work at tremendous speeds, and our eyes are easily deceived. As you know from the cinema, if the eye is presented with a rapid succession of pictures, it 'carries over' its impressions from one to the next, so that the picture appears continuous and gives the illusion of motion

In television a sufficient number of pictures have to be transmitted every second to give this illusion of movement, and thirty have been found to be sufficient. But there is another complication We cannot transmit the picture as it stands since only one signal can pass over the ether at a time. So it was necessary to devise some means of breaking down the picture into pieces, transmitting them over the ether, and reassembling them Also, we must transmit a sufficient number of 'bits' to give the appearance of continuity, just as the little dots of light and shade in a newspaper-picture give the illusion that there is a whole picture

This was done at first by a mechanical scanner which moved a light very rapidly over the scene to be transmitted, the degrees of light and shade reflected being interpreted in terms of variations of an electric current. The modern television transmitter uses a different system to achieve the same end The light from the scene enters what is called a television camera, and is in fact a camera which has, instead of a light-sensitive plate, one that interprets light in terms of electricity. The picture passes through a lens and falls on this plate, which consists of many thousands of miniature photo-electric cells, each of which accumulates a charge of electricity in proportion to the amount of light falling on its surface The scanning of this picture is done by a beam of electrons which flashes across the picture at a tremendous speed, actually covering over four hundred lines a second. Television is no longer spoken of in terms of dots but of lines, a series of dots close enough together looking like a line. As each cell is hit by the beam, its charge is released into the output circuit, amplified in the usual way, and then made to modulate ether waves which are broadcast.

At the receiving end the reverse process takes place. Each

signal is amplified and then led to a cathode-ray tube, an apparatus that looks like a gigantic electric lamp with a flattened end on which the picture appears. This flattened end, or screen, is fluorescent. When it is struck by an electron it is lit up, and the effect of thousands of electrons striking it in different places is to produce the illusion of light and shade which we call a picture The signals control the number of electrons released, and as the four hundred-odd lines are flashed across the screen the different parts are lit up one after the other so quickly that there appears to be a continuous picture The complete screen is covered thirty times a second, sufficiently fast to give the illusion of movement at the same time.

This device, described in a few words and which, when you see your first television set, will astonish you for five minutes, has taken thirty years and millions of pounds to develop in the laboratory. The modern televisor is a maze of ingenuity with methods of control to ensure that the receiver is perfectly 'in tune' with the transmitter, and other devices which ensure a perfect picture without any real attention The part that science plays is best appreciated by the fact that four knobs enable you to control the reception of a picture which is produced by a beam of electrons travelling at about two and a half miles a second and actuated by some nine million different ether impulses in that same time.

Present television, because of the short waves which have to be used, can be transmitted only over comparatively short distances, thirty or forty miles. Obviously we shall want everyone in the country to have television in the home, and experiments are being conducted to find the best way to make this possible. One obvious method would be to have a transmitter every few miles, picking up the signals from the main transmitter or receiving them by way of a cable. Unfortunately, owing to the number of signals that have to be received the ordinary telephone wire which successfully carries sound is useless. A special kind of conductor called a coaxial cable has been devised, and although it is expensive to produce, eventually we may expect Britain to be covered by a network of these cables, carrying television signals from the studios to be 'broadcast' from local stations The range of a television transmitter depends partly upon its height; the greater the height the greater the range. If we could have transmitters at 20,000 or more feet they would have a far greater range and fewer would be

needed to cover the whole country. In the United States experiments have been carried out in sending television programmes from aircraft flying in circles at great heights, the signals being sent from the studio on the ground to the aeroplane for re-transmission. Only a few aircraft would be needed to cover a country even as big as the U.S A. Another suggestion—for the far-distant future—is that an artificial 'planet' might be rocket-propelled to take up a convenient orbit round the earth. From here signals could be broadcast covering the whole earth

The television industry is just being born, and it owes everything to those who for years have striven to master the secrets of transmitting pictures through the ether Thirty years ago they were told that 'it is all very interesting but would never really become a thing for the ordinary man'. But the crude pictures of yesterday have to-day become as vital as those of the cinema, and the industry is one with enormous possibilities for amusement, education, news, commerce, and even for peace by bringing about a better understanding between the nations

CHAPTER XV

INDUSTRY'S MOST OBEDIENT SERVANT

WHAT is it that will 'taste' beer for purity, warn you of a fire or a burglary at home, arrange cigarettes with their names uppermost, switch the lights on when it is dark, tell you when your chimney is smoking, and without which television and talking films would be nearly impossible? It sounds like the subject of a riddle, but in truth it is one of the most useful servants of industry, one that performs a thousand different tasks of which the above are only a few Technically it is a photo-electric cell, but it is also known as the 'electric eye', and by other nicknames Forty years ago the light-sensitive cell was a laboratory toy Few people guessed the part it was destined to fill in our everyday lives when perfected. To-day it carries out hundreds of tedious tasks at a speed greater than the human eye can work These cover a wide range of industries, and vary from working pedestrian-crossing lights to telling the correct exposure for a photograph

The photo-electric cell is really a special kind of valve resembling that used in a wireless set, but it is sensitive to light, and in response to a greater or less degree of light varies the amount of electric current it allows to pass, or, when it is designed for this purpose, allows no electricity to pass after the light has diminished beyond a certain point.

The earliest forms of light-sensitive cell were made with the element selenium, which possesses the property of being sensitive to light in terms of electrical resistance. These cells had the disadvantage that they varied greatly in sensitivity according to the temperature and other factors not easily controlled Nevertheless, they did show the important work that could be done by a completely reliable photo-electric cell. One of these was set to control a lamp in a London suburb. When the daylight diminished beyond a certain degree the cell allowed more current to pass and the lamp was switched on. When the darkness gave way to light the current was cut off and the lamp switched out The cell was not sufficiently reliable, however, for purposes where extremely accurate response to small variations in the amount of light was desirable, so it was necessary to seek other substances which were 'photo-electric' and more reliable.

No other naturally sensitive substance like selenium was found, but it was soon discovered that the metals potassium, caesium, and calcium would respond to light under certain conditions, and so the modern photo-electric cell was evolved In this valve the metal is deposited as a very thin layer usually over silver inside the glass This is the cathode or negative electrode. The anode or positive electrode is of nickel When a light falls on the potassium or other sensitive metal it sends out electrons which are naturally attracted to the anode, and this stream of electrons closes the electric circuit of which the valve is a part They may be likened to a drawbridge which is let down, completing a road which cannot be crossed when the bridge is up, and you will appreciate that if the valve is incorporated in a circuit, this circuit will only be closed when light falls on the metal in the valve to make it shoot out the bridging electrons In comparatively recent times other elements such as caesium have been preferred to potassium or calcium for most photo-electric cells, but the principle remains exactly the same, the preference being due simply to certain qualities notable for stability or sensitivity under varying conditions

The simplest way in which industry puts this wonderful valve to work is to make it close or open an electric circuit in response to light and shade Let us take pedestrian-crossing lights as an example A beam of light is focused, across the path of anyone wishing to cross the road, on to a photo-electric cell on the other side As long as the beam remains shining the lights on the road are green, giving motor-cars the right of way But when someone begins to cross he steps between the light source and the photo-electric cell, momentarily breaking the beam of light Instantly the stream of electrons in the valve is broken The lights on the road show amber and then red, making the crossing safe for the pedestrian waiting at the edge By means of relays the right of way remains open for the pedestrian for a given time, thirty seconds or a minute, when it is restored to the motor traffic, or the change may be brought about by another light working across the road

By light rays focused across the road it is possible to have motor-cars controlling the lights at cross-roads All that is necessary is an apparatus similar to the pedestrian type across each side road Normally the traffic on the main road has the right of way by the

lights. But if a car comes down a side road it momentarily throws a shadow on the photo-electric cell, and this changes the lights to 'Stop' for the main-road traffic Installations of this type have been made, but generally in Britain the type having a 'strip' on the road is preferred: it is less temptation to small children who like to see the lights change In this system of traffic control the weight of each vehicle passing over a strip in the road sends a small electric charge to a condenser; when the condenser has received sufficient charges it discharges, changing the lights through relays.

This 'on and off' setting of the photo-electric cell has a hundred uses. One of them is a burglar alarm If you surround a safe with beams across the door and windows, it is impossible for anyone to approach the safe without breaking the circuit, which in this case has the result of setting off a burglar alarm, perhaps in the nearest police station. Obviously, if a burglar saw a ray of light in front of a safe he might duck under it and thus avoid setting off the alarm, and therefore for this type of installation an 'invisible ray' is used This is often a ray of infra-red light which is just beyond the visible spectrum Our eyes are not sensitive to it, and therefore when it falls on an object it does not appear to give illumination. But the photo-electric cell is remarkably sensitive to this part of the spectrum, and responds in exactly the same way as to white light. The burglar sees nothing, casts an 'invisible' shadow on the cell, and sets off the alarm

At a London exhibition some time ago a valuable jewel was left apparently unprotected. But anyone who reached out a hand for it immediately set bells ringing and brought everyone in the place running. Invisible rays may be a finer protection than steel bars, for these can be cut, whereas the sensitivity of the photo-electric cell is such that even an attempt at tampering would sound the alarm

This simple 'off and on' setting explains how, for instance, the photo-electric cell is used to prevent a lift starting or stopping until all the passengers are in or out. The lift-control mechanism is incorporated in the circuit containing the valve, and this circuit cannot be closed as long as a shadow is falling on the photo-electric cell, that is to say, whenever anyone is entering or leaving the lift

The opening and shutting of doors can be worked on the same principle In a restaurant, for instance, waitresses may have to open a 'service' door when they are carrying a heavily laden tray

Usually they do this by kicking it or pushing it with their bodies It is much more convenient to have a beam of light focused on a valve a few feet in front of the door and connected to a circuit which opens and shuts the door by means of electro-magnets When the ray is broken the electro-magnets come into action, the door swings open as if by magic for the waitress, and then, through a relay, closes as soon as she has passed through.

This device has been used to open and close doors in many places where it is useful, notably in mines where men might not only be heavily laden, but might also forget to close the door, with serious consequences if there were an explosion. We may even look forward to the time when 'Please shut the door' will be an unnecessary notice anywhere. An amusing use of the ray in this way is over low entrances where people systematically bump their heads on the ceiling A ray focused an inch below the maximum height can be made to ring a warning bell, work a sound track shouting 'Mind your head!', or otherwise give warning This device is used on the famous road tunnel at Liverpool under the Mersey to warn lorries that are too high that they cannot pass safely through. No time is wasted in stopping and in measuring loads The ray, working like the height-gauges you see at goods stations, is broken if the load is too high and rings a warning bell

The photo-electric cell can be used not only to switch on and off a current, but also to decrease or increase its amount in response to an increase or decrease in the amount of light This enables the cell to be used as an 'exposure meter' Usually these meters have cells which generate their own current, which may be amplified to move a small pointer The greater the amount of light, the greater the movement, and the photographer is thus able to see instantly the amount of light available at a given spot The most reliable alternative is to count the time required for a piece of light-sensitive paper to change to a standard colour, but the photo-electric meter gives an instant reading, a great advantage in many cases. Moreover, there is no question of personal error in comparing colours

Incidentally, matching colours is one of the jobs that an electric eye can perform It can be made so sensitive to the amount of light reflected that it will cease to act if it is shown the wrong colour. Some of the applications of this in industry are matching cigars to ensure that they are all the same colour; examining

bank-notes to see that all are exactly the same shade and thus eliminating forgeries, and rejecting imperfectly finished goods—for example, packages bearing no label or with the label incorrectly attached. Even eggs are graded and sorted by photo-electric cells, and there is a calculating machine which uses the same principle.

Photo-electric cells are also made to measure temperature The first method of doing this was to arrange slits at certain points in a mercury thermometer, with light rays focused through them on to the cell The rising or falling of the mercury opened or shut these slits, so that the light was switched on or off and the photo-electric valve opened or closed But the sensitivity of the cell to infra-red light enables heat measurements to be made with greater accuracy, especially in dealing with the heat-treatment of metals. Because the cell is so sensitive, adjustment has to be made for the time of day owing to the sun's rays increasing in strength towards noon, but in the latest types a filter which completely eliminates the sun is fitted The normal current from the cells is, of course, greatly amplified for visual reading A typical use of the photo-electric thermometer in industry is for ensuring that iron to be cast is at the correct temperature as it leaves the cupola, but a cell can also measure the heat of the stars and be made so sensitive that it can detect the heat of a candle many miles away

It would be almost impossible to list all the thousand and one uses which have been found for the photo-electric cell in industry. In the great motor-manufacturing plants of America dozens of photo-electric cells are used at different points to ensure that various tasks are correctly done, or properly timed to ensure the proper flow of material. Hundreds of factories use the cell for counting If a number of packages are passing on a conveyer band, and a ray of light is focused across the band, each will break the ray and cast a shadow on the cell. The switching off in this case is made to work a counting device, and thus, without any human being intervening, it is possible to register the exact numbers of any article being made.

This system applies whether the packages are jars of cold cream in cardboard boxes or minute nuts and bolts—it is merely a matter of adjusting the ray to the correct position The cell can be made so sensitive that it will count pieces of paper This was actually done in a U S.A works printing banknotes to ensure that every strip of paper was accounted for. By placing the cells very

accurately, the size of the articles passing in front of them can be measured to within 1/10,000th of an inch Any article above or below the correct measurement is immediately swung out as faulty by a mechanism working from the cell

The photo-electric cell's ability to measure the amount of light falling on it is used in several interesting ways. For instance, brewers have arranged a ray of light to pass through the beer as it flows to the vats While the beer remains reasonably clear all is well But immediately it becomes cloudy the amount of light is diminished, the photo-electric valve is opened, and either a warning sounded or the machine stopped Similarly, in some liners fitted with air-conditioning plant a ray is made to cross one of the large air-ducts While the air is clear the circuit is closed, but if it should become cloudy from an undue amount of smoke the valve is opened and a warning sounded. Thus a fire in one of the holds would be discovered by the photo-electric cell long before the smoke was visible outside One firm had many complaints about the amount of smoke emitted by their chimney. They fixed a ray mechanism across the top and have now immediate warning when the smoke passes a certain density.

Turning on the water of a public fountain when someone approaches to drink, counting the number of people entering a theatre or other public building, counting the movements of a pendulum and thus making a perfectly 'free clock', recording the speed of motorists over a measured distance on roads and warning police ahead of any breakage of the speed limit, grading fruit, inspecting safety-razor blades to ensure their sharpness—these are only a few of the other uses of the photo-electric cell It counts, inspects, sets machines in motion or stops them for safety When we remember that without the photo-electric cell it would be extremely difficult to have either 'talkies' or television, we may well wonder whether this is not the most all-round useful invention of the age. Electricity in its many developments is making the lives of everyone easier and more comfortable, and every kind of work less costly both in time and human effort

CHAPTER XVI

ELECTRONICS

THE invention of the electronic 'tube' or valve with its application to industry may well prove as revolutionary as were the beginnings of steam power and almost as far-reaching in its result. In the electronic tube electrons are harnessed to perform a very wide variety of actions, and it may be stated that there is now no problem of control which can be turned into electrical terms that cannot be solved by electronic devices. The possibilities of automatic control of mechanical processes are enormous To-day, testing, sorting, measuring, and analysing of the most complicated kind can be carried out automatically, not only with greater accuracy than when human operators are employed, but far more quickly The speed at which the most skilled human hand and eye can work is limited. But the electron travels at the speed of light, approximately 186,000 miles a second, which for most practical purposes can be called 'instantaneous'.

Electrons in industry are not limited to mere control Electrons can be made to produce mechanical and physiological effects varying from the production of light to the recording of invisible objects 'Electronics', as the new industrial science is called, is already taking a leading part in our factories and is destined to become still more important. A few examples of the different kinds of work carried out by 'controlled' electrons will show what is being done and what are the possibilities for the future

'Fluorescent lamps' are becoming more general. Certainly in the next few years they will be a familiar sight when their use has spread from factories and offices to private houses In this lamp, instead of producing light by making a wire incandescent as in the ordinary electric lamp, light is produced by the impact of electrons on a chemically coated screen. The impact of each electron produces a flash of light and the impact of many millions produces a continuous glow The advantages over the ordinary type of electric bulb lamp are many.

Firstly, the ordinary lamp does not give the same mixture of different light wave-lengths as light from the sun Any woman knows the impossibility of matching colours by artificial light, because the ingredients of the artificial light are different from

those of daylight; there is generally too much red and not enough blue, with the result that the colours appear different With fluorescent lighting, by varying the chemicals on the screen which the electrons strike we can produce almost any desired colour or mixture of colours. Examples of the chemicals used are zinc silicate, calcium tungstate, and cadmium borate A little more, or little less, of one or the other enables us to control the spectrum of the light produced within narrow limits, so that we can obtain a light which approximates very closely to natural daylight or which can be varied in some other way for a particular purpose.

Another advantage of electronic or fluorescent lighting is that more economic use of the electrical energy is made In the ordinary lamp a very great proportion of the energy consumed is wasted as heat, wasted because it is light and not heat that is required from a lamp Much less energy is turned into heat in the fluorescent lamp and a far greater degree of economy is achieved Yet another valuable feature is that instead of the light-source being comparatively small, a mere piece of delicate incandescent wire, it can be large in the fluorescent lamp if required Most of these lamps are built as tubes several feet long and mounted in reflectors. The light comes from the whole length of this tube, the shadows are very much less dense, and the light is more restful to the eyes. For certain purposes, such as delicate mechanical manipulation or surgical operations, illumination can be made almost entirely shadowless

Another way in which electrons are being put to work in industry is in the collection of dust or the dissipation of smoke. The principle is quite simple Most people know that oppositely charged particles attract each other Electrons produced by special valves or 'tubes' convey minute electrical charges to the dust floating in the air. These particles are then attracted to a metal plate or other device on which the opposite charge is maintained The dust is collected out of the air before it has the opportunity to settle. The charges, of course, have no effect on human beings near by. At the moment this plan is being largely used in factories where the removal of dust may be essential to maintain the purity of products or the safety of workers; an atmosphere charged with minute particles of some apparently uninflammable substances can be highly explosive and very dangerous to health. But presently we shall see these installations in large offices and then in dwelling-houses, so that

the old broom and dustpan will disappear. The duster will not be needed, for dust will be picked up by an electronic collector, perhaps hidden in the ceiling, as it is formed and before it has any opportunity to settle. The consumption of electricity is small.

A similar apparatus can be used in smoke-stacks and funnels for eliminating particles of smoke too small to be caught in ordinary filters. The minute particles can either be attracted to metal plates which are periodically cleaned, or made to join together to form larger and heavier particles which are easily collected.

Electronic generators producing high-frequency currents are being more and more used for welding. We are all familiar with the usual welding outfit, the operator wearing protective clothing and glasses to shield him from the intense light and heat. In electronic welding there is little of this waste of heat and light. The metals to be welded can be held with the naked fingers within an inch or two of the join without even warmth being felt. The heat is produced 'inside' the metal by heavy high-frequency currents and can be restricted to a very small area. The high-frequency currents, as it were, 'jostle' the molecules in the metal so that, rubbing together, they make themselves very hot. The advantages, apart from ease in handling, are considerable. There is, for example, little weakening or even discoloration of the metals because the heat is concentrated in layers only a few molecules thick.

The war saw rapid advances in electronic welding, which was of the greatest help in all aircraft construction. It makes it possible to weld thin sheets of aluminium without burning the metal, and in the not so distant future we may see the whole rather clumsy business of riveting, bolting, and other joining completely replaced by electronic welding.

There is another kind of electronic welding which is being increasingly used in industry. In this case high-frequency waves, not unlike those used in wireless for communication, produce molecular friction which causes plastics to 'set'. Plastic fabrics can be 'sewn' together in this way without any stitches. In practice, the two edges to be joined are passed through rollers in which the high-frequency waves are generated. As the edges pass through, the plastics set together and become firmly fixed. This is how many of the plastic fabric objects such as tobacco-pouches and mackintoshes are produced. In due course we may see the system extended until stitchless clothes are a commonplace.

Electronic heating is being used in the food industries for dehydrating, sterilizing, and cooking Food is generally composed of non-conducting materials. The 'oven' therefore consists of two metal plates into which the necessary high-frequency currents, produced and controlled by electronic devices, are fed. The foodstuff to be treated is placed between the plates and the heat is generated internally in it, instead of being conveyed to it by conduction or radiation as in orthodox cooking over a flame The advantages are numerous There is complete control of the heat generated which is evenly distributed Thus it is possible to bake bread in an electronic oven so that there is no crust Pies and similar dishes can be kept warm for long periods without becoming 'dried up' The close control means great advantages in cooking and manufacturing processes where it is important to avoid overheating, electronic heating is especially useful to the confectionery industry Among other industries which have used electronic cooking are the coffee and cocoa plants where better roasting of the beans can be carried out. In the ordinary cooking of meats for preserving there is the great advantage of time saved, the time required for electronic cooking may eventually be only one-twelfth that of the old methods.

Electronic ovens for home use have been constructed and pictures have been painted of the housewife of the future cooking her joint and two vegetables to perfection in four minutes. It is perhaps possible But the installation is complicated compared with the ordinary electric oven and, although it uses no more electricity, the initial cost is such that there is little likelihood of electronic cooking adapting itself from factories to the home in the near future

For dehydration the great advantage of electronic heat is that a much higher percentage of moisture can be removed without burning or loss of flavour This is particularly important for the storage of food over a long period or for its export to tropical countries Sterilization is nearly always carried out rapidly.

The sterilization of food by electronic heat leads to another application of electronics, the destruction of insect pests High-frequency currents of the right type destroy flies, weevils, and other pests with great certainty. Wheat can be made insect-free by passing it between metal plates Any pests are, as it were, 'shaken to death', but the wheat itself remains unaffected. The

grains need to remain only 20–30 seconds between the plates It is thus possible to treat large quantities of wheat in storage without resorting to insecticides or other chemicals In the same way electronic 'screens' can be erected in front of open windows There is nothing to see, but the invisible electronic 'screen' over the window means death to any fly, mosquito, or other insect that attempts to pass through its field.

But it is in the control of machinery and manufacturing processes of all kinds that we find electronics performing its most astonishing tasks. For all electronic control it is necessary that physical changes or measures should first be converted into electrical terms. This may be done with the aid of photo-electric cells which convert variations of light into changes of current as described previously, by thermo-couples which convert variations of temperature into electrical change, or by 'pick-ups' which turn mechanical into electrical vibration. We all know simple examples of the use of these devices; the photo-electric cell is one of the secrets of the 'talkie' projector, converting the shadows on the film into the electrical impulses which, in due course, are turned into sound Thermo-couples on our gas and electric ovens regulate the amount of heat The 'pick-up' is familiar in the radiogram, where it turns the mechanical vibrations of the needle in the sound grooves of the record into electrical impulses which are amplified and converted back into mechanical movement in the loud-speaker.

A number of applications of the photo-electric cell to industry have been mentioned, but in the last ten years its possibilities have been greatly increased in conjunction with another electronic device, the cathode-ray tube. It is the end of this tube that is the screen of a television receiver. Electrical impulses are interpreted in terms of a stream of electrons which, striking the specially coated end of the tube, produce minute flashes of light These make the 'picture' on the television screen. When the cathode-ray tube is used for industrial testing purposes, the principle is the same, but instead of light and shadow representing a 'picture', we have the visual representation of electrical resistances. The variations in light intensity noted by a photo-electric cell, for example, are turned into variations of an electric current which in turn, when 'fed' to the cathode-ray tube, produce a 'picture'. It is not a picture of the television type, but represents the change

in electrical resistance that occurs when a sample of steel, for example, is incorporated in the circuit

The 'picture' made by a standard sample is known and may be marked permanently on the screen. Each piece to be tested has then merely to be placed between contacts, when its 'picture' appears on the screen. If this does not coincide with the standard picture, the operator knows that the specimen under test is in some way different and should be rejected. The tests can be carried out as fast as the operator can place the specimens in position and a girl, after little training, can thus carry out tests which only a few years ago might have taken a skilled scientist many hours But the matter has been carried farther Watching the darkened screen is tiring Electronic engineers have therefore set up a photo-electric cell to watch the screen The curve of the standard sample is covered, so that only something which is not coincident with this curve can show This means that if anything passes the screen its appearance is recorded by the photo-electric cell, and by the use of amplifiers and relays the specimen under test which is not according to standard can be rejected

An apparatus of this type is used for automatically testing wireless valves The voltages are carried to a cathode-ray tube where they are displayed on the screen as a curve A mask prevents the curve being seen if the characteristics of the valve are according to specifications If any light is 'seen' by the photo-electric tube 'watching' the cathode-ray screen, it immediately brings into play a rejecting device through an amplifier and relay

By a slight adaptation of this system, coloured objects are sorted with great precision Tiles coming from a kiln, dyed textiles, and in fact any kind of coloured object can be 'inspected'. Monochromatic light is used to record the colour of the specimen under test in electrical terms. The electrical 'reading' is passed to a cathode-ray tube where its coincidence or divergence from a standard 'picture' is observed. In practice specimens are not required to conform exactly to the picture of a perfect specimen. A certain tolerance is permitted, the standard 'picture' on the screen being a composite of all samples falling with the limits.

Many thousands of applications of electronic control based on these principles have already been made It is difficult to conceive of a problem of control or test that could not be solved electronically It has been suggested, for instance, that by using a code of dots to

replace the normal city numbers on addresses, letters could be electronically sorted. Photo-electric tubes would 'read' the codes and divert the letters accordingly.

Space prevents detailed description of the many hundreds of uses of electronics in industry, but a list will give some idea of their wide range:

Smoke-detection to give early warning of fire.

Flame-failure detection

Sorting nuts and bolts according to size and metallurgical analysis

Automatic detection of flaws in metallic objects.

Automatic recording of river and reservoir levels to give flood warnings.

Inspection of aircraft engines for any flaw, from a faulty plug to concealed cracks.

'Monitoring' telephone conversations to ensure the volume of sound being constant whether the speaker is speaking loudly or softly, near or far from the mouthpiece

The regulation of watches and precision timekeepers, gain or loss being instantly revealed in terms of light on a cathode-ray tube screen.

Inspection of unused film in pitch darkness.

Automatically guiding flame-cutters around a template.

High-speed automatic testing of complex electrical circuits

Automatic measurement of the cloud ceiling and other meteorological data.

Measurement of 'starlight'. The minimum amount of light measurable by electronic devices is one-hundredth of a million-millionth of that of the ordinary electric lamp Measurement of these minute changes enables astronomers to estimate speed and direction of star movements.

These are samples only. In the chemical industry alone, there are many hundreds of automatic control devices based on electronic measurement of opaqueness and electronic precipitation of moisture or impurities

We come now to another application of the electron beam in industry which is of the greatest value. Up to a few years ago it appeared that man had reached the limit in magnification of objects invisible to the naked eye The limit was prescribed by the wavelength of light However good the optical system, it would not be

possible to see objects of less than a certain size because the light with which we see would 'slip' between them and no light would be reflected to give an image The range was slightly extended by the use of ultra-violet light which has a rather shorter wave-length, but beyond this it seemed impossible to go Then came the idea of substituting a beam of electrons for a beam of light. Having a much smaller 'wave-length' this would strike very much smaller objects and bring into visibility a whole range of detail never seen with the human eye together with objects invisible under the most powerful microscope

In the thirties, with much patience and skill, the electron microscope was perfected and to-day magnifications up to 50,000 and even 100,000 are possible. We can now observe bacteria which previously seemed destined always to be invisible and see details of such things as smoke particles which were quite invisible under the ordinary microscope. In the electron microscope a beam of electrons replaces the beam of light of the normal microscope It is focused or refracted in the same way, except that the lenses are magnets instead of pieces of glass The beam strikes the object being examined, some electrons pass on while others are stopped. The shadow of the object as outlined by the electrons is not, of course, visible to the naked eye. To make it visible the beam is thrown on to a chemically treated screen where the impact of each electron causes a momentary fluorescence which is visible to the human eye.

These electron microscopes, although easily controlled, are large and very expensive something over £20,000 each But they are proving indispensable to industry for research, and in medicine have made possible the detailed study of viruses of which the shape and structure were hitherto quite unknown Among industrial problems that have been studied with the aid of this microscope are the structure of textile fibres, highly important in the production of synthetic textiles and the improvement of natural fibres; the purification of lubricating oil; the structure of paper with reference to its resistance to grease or moisture; and the structure of steel, which determines its properties. The apparatus is also being applied to plastics and synthetic chemistry, since the magnification is such that the larger molecules can be made visible, but it would be difficult to think of any industry that will not eventually benefit from research carried out with the electron microscope.

An invention based on the same principle as the electron microscope is the electronic analyser. This device can analyse for the chemist the composition of gases of great complexity. It does the work in about 15 minutes where, perhaps, 15 hours would be required by a team of experts. The importance of this is that, in many industrial processes, inspection has to be speedy as well as constant. In the manufacture of synthetic rubber the products must be analysed for purity at every stage If the very complex molecules have to be analysed 'by hand', it means long and wasteful delays. The materials cannot pass on to the next process until the chemist has given the word The electronic analyser or spectrometer supplies the answer in a few minutes.

In the analyser, the beam of electrons, instead of being flooded on the whole object to be examined, is concentrated on one minute part of it, perhaps a 'single molecule' The electrons pass into the different elements making up the substance and emerge at different speeds according to the atomic weight of the element they have encountered Instead of being carried to a fluorescent screen, they are bent according to their velocity and allowed to fall on a photographic plate The picture on the plate shows the number of electrons arriving at different speeds, and from this the elements making up the object under test can be determined. The chemist is thus able to analyse a minute quantity of material, too small even to see The elements making up a molecule of protein or the chemicals present in a virus can be determined.

These are some of the applications of the electron to industry and it is worth noting that all this 'magic' is carried out by particles weighing an almost incredibly small amount The weight of the electrons passing through a typical electronic device in a year has been calculated at 4 lb and their number as 2 followed by 30 noughts.

There remains one very important development in electronics, although it is not at present much used in what we generally call 'industry'. That is radar The application of radar to the problems of air and sea navigation are considered in their appropriate chapters. Radar is 'wireless' with a difference. Instead of the signals sent out by the radar transmitter being 'waves', they are pulses, little groups of signals with an interval The speed is too great and the intervals are far too short to be measured by the human eye, but the electronic devices work so fast that they are able to

measure time-intervals of millionths of a second. They can measure the time taken for a signal to travel as little as 200 yards and be echoed back The signals received are fed to a cathode-ray tube and produce a 'picture' Instead of the curve of the resistance of steel we may get a 'pip' indicating the direction and distance of a reflecting object or a complete plan picture, showing the position of all the reflecting surfaces in the neighbourhood.

Radar is chiefly used for transport, but there are other applications and many possibilities for the future It has great uses in meteorology. Raindrops may reflect suitable radar signals and thus enable meteorologists to measure the distance of clouds with great accuracy for forecasting. Similar pulses may be used for discovering the position of buried metal, oil, and ores. Most important, perhaps, has been the development of special valves capable of sending pulses of enormous power. This is not quite the same as the transmission of high-powered 'wave' signals, for the whole output is concentrated in a 'surge', but it should help to pave the way to the direct transmission of energy for power and lighting by wireless in the very distant future, or, nearer to our time, the use of inductive transmission for electrical transport on the roads

CHAPTER XVII

SCIENCE GOES FARMING

TOWARDS the end of the eighteenth century quite a number of so-called economists were seriously perturbed at the possibility of the world facing starvation in the near future They noted the rapid increase of population, and argued that we should not be able to grow sufficient food to fill all the new mouths that were going to be born. According to their forecasts there should be a great shortage of food to-day, for the increase in population has been fully what they expected.

But in fact, if we except the shortages due to war destruction, there are immense supplies in the world and it is not so long ago that almost every country was deliberately restricting its agricultural output Some were actually destroying food for which no market could be found, though it is true that this was chiefly due to lack of transport

Where were these forecasters wrong? They did not foresee the scientific developments which would take place, enabling two bushels or more of wheat to be grown where before there was one Nor did they grasp the possibility of improved plants to resist pests and disease, or of animals scientifically bred to suit the purpose for which they were intended. They did not foresee, in fact, that farming, which is, and probably will remain for many years, the one fundamental industry, would become a science instead of a rule-of-thumb craft. The changes that science has brought to farming have been so tremendous that only a few of those most interesting can now be mentioned. The change is due to a complete alteration of mental attitude in regard to foods and produce.

Where the eighteenth-century farmer would decide what crop to grow on a particular piece of land, no doubt by a curious combination of experience and guess-work, his modern scientific counterpart will undertake a soil analysis, and if he finds the earth deficient in any of the minerals which the laboratory knows to be necessary for the good growth of a particular crop, he may choose another type better suited to the land, or make good the chemical deficiences. The old-fashioned farmer used to take seeds from his own crops or from a dealer, perhaps without inquiring into their ancestry for more than a generation, the modern farmer uses seeds from

plants which have been selected and crossed, maybe for a dozen generations, specially to ensure that the plants shall be of a certain size, shape, or colour, resistance to cold, drought, or certain diseases

The question of producing the 'best' thing, whether it is lettuce or sheep, is so important that perhaps we might consider it briefly here. During the latter half of the nineteenth century that mysterious thing called heredity was investigated scientifically. Men had always realized, of course, that certain characteristics in animals and plants, no less than in themselves, were passed on from generation to generation The heredity principle in law is based on this But they did not understand why sometimes a plant did not produce seeds according to its type, nor how to improve the plant by adding to its desirable qualities other desirable qualities from other plants. The research of Mendel and others showed how such characteristics as colour were transmitted from generation to generation, and how we can by the process of selection obtain, for instance, a desired colour in a flower. If for colour we substitute height, size of flowers, resistance to cold, resistance to disease, and other qualities in turn, we get a glimpse of the wonderful science by which plants are 'made to order'.

Fifty years of research and the lifework of many brilliant scientists contribute to even the simple packet of seeds you plant in your garden. The qualities desired are added one by one until the final plant has all of them. It is even possible to produce new plants and fruits. The loganberry is a result of breeding of this kind.

This process has been applied to everything the farmer grows A wild plant is taken which is moderately rich in sugar, and improved by scientific principles until at last we have the sugar-beet, so rich in sugar that it is an alternative natural source to the sugar-cane. Sir Walter Raleigh, the traditional discoverer of potatoes, would not recognize the potatoes we grow to-day, infinitely better in flavour, shape, and size than those of his time. Luther Burbank, the American scientist who did more for gardening than any other man, by his improvements to the potato alone is estimated to have increased the value of the American crop by £5,000,000 a year. He took the prickly pear, one of the pests of the desert, and improved it until he had a 'pear' that was not prickly and which cattle liked. He thus made it possible to grow cattle food where before had only been desert.

These principles can be applied to animals equally with plants, and the stockbreeder to-day must be something of an expert in the science of genetics, the science of dealing with heredity, and even in the principles of grafting This science has enabled us to have cows giving twice the previous yield of milk, to breed sheep with the kind of wool most desired for making cloth, and poultry which lay more eggs. An interesting illustration of the power now in the hands of the farmer is the breeding of animals to keep pace with the modern fashion for very small joints

There was systematic breeding before the beginnings of the modern science of genetics, but because people did not know why, they had to work by trial and error Now the farmer may set scientists a particular task and be reasonably sure it will be solved for him For instance, he may ask for a wheat that matures very quickly so that it can be grown in northerly regions which have hitherto been considered to have too short a summer for wheat-growing. The scientist will produce it almost at once If a disease, such as rust, strikes a crop, from the laboratory will come new plants which resist this disease. Where crops cannot be made immune to pests, chemicals will be devised which destroy them, or we may even breed other insects that prey on the undesired families and thus keep down their numbers. Scientists in laboratories in many countries work year in year out solving these problems for farmers, the results of all their investigations always being that more food is grown at a lower cost.

Outwardly, perhaps, the most striking change that science has brought to farming is the introduction of machinery It is certainly true that the people of the world could not be fed unless there was machinery. We could not plant the wheat, and there would not be enough men to reap it when it was ripe. The reaper, which represented the first really fundamental change in agriculture for centuries, made possible as much bread as anyone wanted at a few pence a loaf. It was the greatest agricultural invention of the last century. The tractor, an offspring of the motor-car, enabled the reaper, the plough, and other implements to be worked faster and with less labour.

To-day, there is machinery to perform almost every task on the farm. Cows are milked by machinery, and the milk is cleaner and better than before. Incidentally, it is sure to be scientifically tested for its content of fat, mineral matter, and

bacteria before being sterilized and bottled—of course by machinery. There are machines to lift potatoes and beets, to spread manure or fertilizer, and to carry out almost every task that was formerly done by labourers.

Some idea of the change that the tractor has made can be gathered from the statement that there are drills covering twenty-four rows at a time, and fertilizer distributors that cover 27 feet at a time. It has been estimated that machinery has increased the yield of crops twenty-fold Where perhaps thirty hours of labour were required to cultivate and crop an acre of land, to-day machinery makes it possible to deal with the same land in five hours. This is, of course, quite apart from any increased yield due to improved plants.

One of the greatest things that science has done for the farmer is to remove much of the element of chance from his business. The biggest doubt in farming has always been the weather. We have not yet learned to control the weather, in spite of experiments with cloud guns, and sand dropped by aeroplanes to enable moisture to coagulate. The most we can do for the farmer in this direction is to give him a forty-eight-hour forecast so that he can decide when to mow his hay or reap his wheat But we can reduce harmful effects of undesirable weather. This is done in so many ways that they can only be mentioned by name.

First there is irrigation which overcomes drought, quite apart from bringing into cultivation millions of acres that would otherwise have remained barren. Then there are anti-frost measures, glasshouses which admit the sun but keep out rain, snow, hail, and frost. Where poultry is concerned, even the sun may be artificial, while the doubts of a mothering hen are removed by incubation with a machine, thermostatically controlled so that the temperature is automatically and correctly regulated at all times For fruit-trees, we have burners which are lit when the temperature falls to the danger-point in spring, automatic alarms warn the farmer when his fruit blossom is in danger, and enable the burners to be lit. Then we have hay ovens in case it should be a rainy May or June. These ovens are quite independent of the sunshine, are automatic, preserve the vitamin value of the grass, and enable the farmer to do his haymaking without constantly looking at the sky. Apart from these, we have in its infancy the artificial heating of the soil by electricity, which may well develop until whole fields are

treated in this way Radiation of crops and chemical growing are now almost at the commercial stage

As an example of the changes machinery has brought about, compare the poultry farm of, say, fifty years ago with the modern 'battery system'. There are hundreds of fowls that never even see the barnyard. They are kept in wire cages, with conveyer belts to remove the refuse from underneath. They have cod-liver oil as a substitute for the sun, and their carefully measured water and food comes through tubes to the troughs. Using some of the appliances it is said that an acre of ground will accommodate 20,000 fowls, and that one man can look after 10,000. In one farm the fowls are even prepared for the market by machinery, being electrocuted and plucked mechanically

A scientific development of farming that has attracted great attention in recent years is that of growing food without soil. The earth which we cultivate is simply a reservoir of food for plants. The roots of the plants select the minerals they require and these are utilized by the plant in growth In soilless farming the chemicals are measured out and dissolved in water, the plants sending their roots down into the water and taking up the food Because the food is exactly what is required, and the plants are not subjected to the vagaries of the weather, always receiving ideal conditions indoors, the crop is enormously increased In one case with potatoes, for example, the crop was 2,500 bushels to the acre without soil, compared with 120 bushels in soil. The measurement and selection of the chemicals to feed the plants has to be carried out with laboratory accuracy, but most of the difficulties now appear to have been overcome and crops grown under these conditions have been sold on the open market. If this trend continues the farmer may eventually work entirely indoors, but so complete a change is not likely at least for several hundred years.

The farmer who, until this century, was almost wholly concerned in producing articles to eat is about to enter a new field and become an important link in other industries by supplying their raw material. Already we are using millions of tons of cellulose for various purposes, from the manufacture of explosives to silk stockings The farmer will no doubt extend his scope and supply an increasing proportion of his products to factories for 'building up' into other substances. For example, motor fuel is

now obtained from potatoes and even from grass. Thus the service of science to farming has been to banish the picture of a farmer struggling to produce enough to feed an ever-growing population, and to make it possible for him to consider new crops which will be used not for feeding but for clothing the population, and even providing them with fuel for their motor-cars or ordinary domestic heating. Farming is a scientific and a fascinating occupation in this century.

As a result of war destruction there seems likely to be a shortage of food, at least until 1949, but this is probably only a temporary phase. War destruction apart, it could be explained by failure to increase the production of food to keep pace with the increase in population. In spite of the deaths due to the war, the total population of the world between 1939 and 1945 increased by many millions In normal times this would have been accompanied by an increase of food production Once we have 'caught up', made good the destruction of livestock, and begun to feel the possibilities of increased production of mechanical farm tools, we shall produce more food than ever before in the history of the world Moreover, thanks to the scientists' synthesis of new insecticides, we shall sacrifice less of it to insect pests. The amount of food consumed by pests every year is estimated at £1,500,000,000 worth, and it is obvious therefore that the invention of a more efficient insecticide that saves much of this loss is as valuable as the invention of new and more prolific seeds Another important development is the increasing production it is possible to obtain from countries previously considered too cold for valuable crops. By breeding special wheats that mature quickly, agricultural scientists have made it possible to extend the 'wheat line' farther north and bring under the plough millions of acres that formerly yielded nothing.

In the long view, ten or twenty years, the application of science to agriculture makes it reasonable to contemplate for the first time a world in which enough food for everyone is being produced. Always before there have been people who have faced starvation. Lack of transport, alone, has been responsible for many famines.

CHAPTER XVIII

SCIENCE HARNESSES MOULDS

ALL the syntheses which have been described are brought about by the industrial chemist with the aid of heat, pressure, and catalysts, those chemicals which help in the union of other substances but which themselves remain almost unchanged at the end of the reaction. There is another increasingly important type of synthesis which is caused by the use of what might, very non-technically, be called 'living catalysts' The scientist harnesses living organisms to bring about a change in the form of the matter fed to them until the result is some new chemical which he requires A simple case of this kind of synthesis, known to everyone, is the photo-synthesis continuously carried out by plants With the aid of sunlight, they take the carbon dioxide from the air, the moisture and various elements in the ground and synthesize them into extremely complex carbohydrates and other substances The chemist in his laboratory cannot bring about this synthesis by purely inorganic processes. He has not yet been able to imitate the photo-synthesis of plants although, as will be explained, he may be able to do so before very long

The organisms used by the industrial chemist to obtain desirable chemicals can be called generally 'moulds'. We are all familiar with moulds, from those growing on damp ceilings to those which give the flavour we like in certain kinds of cheese Most people realize that moulds are living organisms, their beautiful structure can often be clearly seen under a microscope, or even a magnifying glass. They are an elementary form of living thing, but they eat and multiply very rapidly under favourable conditions In the course of living they take matter in one form and turn it into another. They may use quite simple chemicals such as oxygen, carbon dioxide and water, and turn them into extremely complex materials To many, 'moulds' mean decay, and it is quite true that certain moulds are engaged in the process of breaking down various common substances The by-products of this 'germ activity' are sometimes poisonous. But in an increasing number of cases it is being found that suitable moulds can be extremely useful, building up chemicals that are wanted and not easily obtained by any other means.

The most striking instance in recent years has been the production of the 'wonder drug' penicillin. In this case it was the spores of a mould, alighting by chance on a culture, which started the hunt for a drug sufficiently potent to destroy harmful bacteria while leaving healthy tissues unaffected. It was noticed that where the mould was growing on the culture the growth of the bacteria was completely inhibited. The mould, evidently, was producing some chemical which was 'poison' to the bacteria.

The story of the discovery and testing of penicillin has been told frequently in recent years. By painstaking work in which many teams of chemists, biologists, and medical workers co-operated, the chemical responsible was isolated and tested first on animals and then on human beings. When it became obvious that here was a medical weapon of great importance and able to save many lives, the demand came for more penicillin. At first the chemical was extremely difficult to produce. The mould had to be suitably grown and the chemical, which was the only part that interested the doctors, laboriously separated and purified. The cost was fantastic and penicillin had to be reserved for the few cases in which it was the only hope.

Engineers then began to take a hand, seeking for methods by which the mould could be dealt with in very much larger quantities, giving a great yield at a lower cost. The problem has been solved by what is called 'submerged culture'. Instead of growing penicillin in hundreds of thousands of milk-bottles, everything being done by hand, the mould is grown 'in depth' as well as on the surface of the medium. The chemical which it makes is handled by large-scale plant and the elaborate purification is carried out in specially designed apparatus, very different from that used in the laboratory, although the principle is the same.

For that matter the mould itself is different from that which first landed on the culture in 1928. Moulds can be bred like dogs or cattle and they can be bred for special purposes. Science has improved the strain of this particular mould, improved it from the point of view of yielding penicillin, as a breed of cows is improved to yield more milk. In fact, the breeding has been far more drastic, for scientists can do things to the comparatively simple mould which they cannot do to the cow. They can use X-rays and drugs like colchicine to alter the hereditary 'make-up' of the

spores. To-day, out of some hundreds of strains of penicillin moulds, four are chiefly used.

We now know the chemical constitution of penicillin. It is very complex, not so much because of the number of atoms of hydrogen, nitrogen, and other particles, but because of their arrangement. It is possible that purely 'synthetic' penicillin, built up without the aid of any living organisms, might have the same formula, but yet not be the same thing At present it seems likely that the mould will continue to be employed for manufacturing penicillin because it is the cheapest and most efficient method we know. The purely chemical synthesis of penicillin would be complicated and, as one biologist wittily put it, 'It's cheaper to employ moulds than it is to employ doctors of science'

Progress in the mass production of penicillin which only a few years ago seemed 'impossible' has been aided by work already done on the mass production of other moulds for quite different purposes There are estimated to be at least 100,000 different moulds in the world and no doubt the possible strains which could be bred artificially are virtually unlimited Only a comparatively small number have been fully investigated and a score or two have been put to useful work. An interesting case is that of the mould *Citromyces* Nearly half a century ago a German chemist discovered accidentally that when this mould fed on sugar it produced citric acid. The discovery was of great importance, for before it the only useful source of citric acid was fresh lemons.

Attempts were made to devise a method by which the experiment could be repeated on a large scale to produce citric acid commercially. But the difficulties were very great. Moulds are living things, neither plant nor animal, but living, and they cannot be treated like inert 'chemicals'. The process remained in the laboratory for many years until it was taken up by United States Government chemists, particularly interested because the United States had to import great quantities of citric acid every year for its soft drinks. Another mould was found to lend itself to control much better, and after ten years' work a commercial process was perfected. The mould, called *Aspergillus niger*, made it possible for the United States to make thousands of tons of citric acid a year without the use of a single lemon

The use of moulds calls for very careful control of conditions, for if these are not exactly right some useless or even poisonous

substance may be produced instead of the desirable result. For example, the mould mentioned can produce oxalic instead of citric acid under certain circumstances Ensuring the right conditions on a large scale has been the stumbling-block in many cases when it has been desired to take a process from the laboratory to the factory. Temperature and atmosphere have to be exact and the 'food' on which the moulds live has to be carefully regulated. It is this 'living' which eventually produces the desired chemical. The moulds require not only 'main meals' but vitamins in the same way as human beings. This fact has been utilized in devising methods of testing the vitamin content of preparations. The rate of growth of moulds dependent upon them can be measured as an alternative to the rather more complicated method of measuring the effect on rats or guinea-pigs.

Among other important substances manufactured with the aid of moulds are calcium gluconate, lactic acid, and fumaric. Calcium gluconate is made from gluconic acid produced with the aid of a mould The chemical can be obtained synthetically without the use of a mould, but the synthesis is difficult and expensive Cheap gluconic combinations with calcium are important because they can be used to control diseases due to calcium deficiency in animals The substance has been used with notable success in treating cattle, giving better milk production and reducing the danger of milk fever. It has been tried experimentally on poultry for better eggs. So long as the price of the chemical was about £30 a pound, its use was severely limited. But production from glucose with the aid of a mould reduced the price to one-twentieth and may bring it to a still lower level.

Lactic acid is a valuable substance in medicine, and fumaric is important in the production of certain plastics These are only examples of the ways in which substances, otherwise unobtainable or extremely expensive, can be made with the aid of moulds. It will be recalled that during the war Dr. Chaim-Weizmann used bacteria to produce the acetone vital to the chemical industry from starch.

The possibilities of making valuable drugs from moulds are only just beginning to be explored. Patulin, which like penicillin is produced by a mould, has been a disappointment in medicine, but has great possibilities in horticulture. It seems to inhibit the bacteria responsible for 'damping off' and other diseases in seed-

lings The opportunities for producing bacteria-attacking chemicals with the help of moulds are tremendous, but there must usually be years of laboratory work before commercial production The chemical has first to be isolated It must then be tested under every condition and the limits of its toxicity on man discovered; a chemical that kills the disease germs is no use if it also injures the patient Then must come the adaptation of the laboratory process to production, so that the drug can be plentifully and cheaply available

Among other processes using moulds and ferments, at present experimental but likely to be developed commercially, is one designed to give an inflammable gas for lighting and heating from waste agricultural material of all kinds, from straw to hedge trimmings. Yet another, still far in the future perhaps, is the use of moulds and bacteria for breaking down the cellulose of wood to produce food We can make sugar from wood by purely chemical synthesis In the near future we may turn wood into food more easily by the aid of living organisms. In fact it is done by Nature every day, there are insects which digest wood by means of bacteria We might be able to produce strains of these bacteria and moulds which will turn sawdust into food that can be eaten by cattle, poultry, and even human beings It would be more valuable than the famous chocolate from coal.

CHAPTER XIX

PRINTING: RECORDING OUR THOUGHTS

PRINTING was one of the most revolutionary inventions because it made possible the distribution of knowledge and learning to a theoretically unlimited number of people. Before printing, word of mouth was the only way of passing information on a large scale. There were books, of course, but as these had to be hand-written they were both rare and expensive. Moreover, with few books there was little opportunity for learning to read and, in fact, reading was at one time a comparatively rare accomplishment, the mark of a scholar. In the beginning printing was hardly a scientific industry; indeed there was no industry as we understand the word to-day. Not only the typesetting, but the very making of type had to be done by hand, and every sheet of paper taken off separately by hand It was a laborious process but much less expensive than the hand-written book

The contribution of science to this industry may be summarized by saying that it has made exceedingly cheap and speedy the production of all kinds of printed matter, so that we can now purchase a daily newspaper for a penny or a book of several hundred pages for a few shillings. It is safe to say that in the early centuries of printing, quite apart from the cost of news collection, a daily paper similar to that which we read to-day would have cost, if it could have been produced at all, many pounds. Even two centuries ago only a few hundred copies a day could have been printed, so that any question of everyone having a paper would have seemed absurd.

Speedy and cheap printing enables us to make the fullest use of the other great inventions which have speeded up communication. Our telegrams would be of little use unless we could quickly distribute them in printed form in our newspapers The value of photography is immensely increased by the possibility of reproducing photographs a very great number of times. Quite apart from its entertainment value printing has had the most far-reaching consequences in education. It was the invention that had to precede others, because there could be little scientific development until the theories and discoveries of notable men could be widely distributed The lack of communication and of

books meant that a particular art or science might be highly developed in one country, whereas little was known of it in another.

To-day, the discoveries of scientists of all kinds are given permanent form and distributed over the whole world in books and journals. It has often happened that a worker in America, engaged on a particular line of research, has read something of work being done in a European country which has thrown light upon his problems. All sciences are interconnected, and the discovery of a biologist to-day may be of the greatest importance to a geologist to-morrow But for printing, exchange of knowledge on any wide scale would be impossible and progress nearly as slow as in the centuries that preceded its invention.

If you walked round a modern newspaper printing-machine you would probably be struck by its great complication. But the principles are comparatively simple, and if you analysed the machines you would find that they are making use of fundamental mechanical devices, many of them known hundreds of years ago. These fundamental methods are found in almost every machine, the toothed wheels or cogs which fit into each other and produce motion at related speeds or directions; the cam, which controls another mechanism by pressing against it at intervals; the lever, and so on. In a complex machine there may be hundreds of parts each performing its task, all their movements related or timed by these basic devices.

Modern printing machinery is, of course, mostly power-driven. There is still much craftsmanship in printing, but we do not ask our printers to use their strength in turning the cylinders or placing the paper. The need of a modern newspaper for producing a large number of copies in the shortest possible time has stimulated the inventor to produce a number of automatic plants, to-day, the sheets are not only printed by machinery but also folded, counted, and delivered to the waiting van without human intervention, except that of control.

The most laborious part of printing in the early days was type-setting. Each letter had to be picked from a different box and placed in position in a 'stick' held in the hand. Type-setters became very fast in their work, but the amount that could be set up in this way in a given time was obviously limited. Nowadays, except for small pieces of work and display, type-setting is carried out by machinery. The operator's work is limited to tapping keys

like those on a typewriter, and he is even assisted mechanically in 'justifying'—the name which printers give to inserting little spaces of varying width between the words to ensure that every line shall be of exactly the same length.

There are a number of different kinds of type-setter, but most of them have this in common, that it is not the actual type which is set but a series of matrices, or moulds, from which the type is cast. What happens in a typical type-setting machine when the operator taps a key representing a letter is that a matrix with a mould of this letter on the end is released from its magazine and travels along by a belt to a box where it is joined in the correct order by other matrices representing the subsequent letters, with little wedges for spacing. When the line is complete the operator presses a lever, and the matrices are carried along to a mould. Just before molten metal is forced against the faces of the letter moulds the line is automatically justified by spaces being pressed up from below, so that the words are neatly spaced to fit exactly into a line of the desired length.

The metal takes the impression of the letters on the matrices and is cast in the form of a 'slug', which is deposited in a holder to await the arrival of the next slug representing the next line. Meanwhile the matrices are released and travel back to their magazines. The method by which they are dropped into their correct position is simple but ingenious. Each letter has a 'code' represented by teeth or cuts in the matrix. As the matrices travel past the magazines, each one eventually comes to a position where its teeth meet, and it drops out. Compare this with the laborious process of taking apart a column of separate pieces of type and dropping them one by one into their correct boxes for use again. The operator does not have to wait for the line to be cast and the matrices to return to their magazines, this process continuing automatically while he is busy with the next line.

Apart from its speed automatic setting has the advantage that no huge stock of type is required, each machine needing only sufficient matrices for two or three lines, the matrices being used over and over again. In other methods of automatic setting the matrices may travel on wires to an assembly point by the force of gravity, so that it is not necessary to cast a whole line of type at one time. One very widely used system, called the 'Monotype', casts each letter separately. In this machine the effect of the operator

touching a letter-key is to punch a hole in a strip of moving paper. The holes are a code, rather like that used in telegraphy; so when the strip of paper is passed through a casting machine, the appropriate letter matrix is selected, cast, and passed along to form complete lines and eventually whole columns Apart from other advantages, this system can be used to cast type for hand-setting, so that, from a set of master matrices, many founts of new type can be quickly and cheaply prepared

When we pass to the actual printing machinery we find two chief types, the flat-bed and the rotary In the flat-bed machine the type is laid face upwards and the paper pressed against it. In the rotary machine, now used where quickness is more important than fine printing, the type is cast into a half-circular plate fixed to cylinders and rolled over the paper as it passes under it in a continuous band Flat-bed machines have progressed far from those used by Gutenberg or Caxton, and even from those used a century ago One automatic device after another has been added to simplify and speed up the process The paper, for instance, may be fed automatically to a machine which ingeniously takes into account the reduction in the height of the pile as one sheet after another passes to the machine. The inking is automatically regulated, so that every page gets the same amount of ink and pressure, giving an even blackness, while a device takes charge of the printed sheets as they are delivered, lowering the piles to the floor as they are made. Many hundreds of inventions applied to the presses enable one man to do the work which formerly would have been done, and not so well, by twenty or more.

In the rotary machine it is necessary to have the printing surface curved. The actual slugs or type set up are not used, a mould being made from them of papier mâché, from which, in turn, a half-cylinder of metal is cast, bearing the impression of the letters on its outer face. This casting may be carried out automatically at the rate of two plates a minute, ready trimmed and with holes pierced for fixing to the cylinders. The cylinders are inked by rollers, and the paper may be printed on both sides by the one machine. A big newspaper press really consists of a number of units, each printing a certain number of pages; then discharging the printed matter to machines which cut and fold the pages before delivering them There are many refinements, such as the machine at the end which can take type at the last minute, and

imprint it in the space marked 'Stop Press'. These machines work up a tremendous speed, using paper by the mile and delivering perhaps 300,000 pages an hour. Even more remarkable is the arrangement which enables new reels of paper to be joined in, or the 'Stop Press' column altered, without stopping the machine.

Printing, more than many industries, has retained its craftsmanship, and for some processes, such as the 'making ready' for a flat-bed press, no machines have been able to take the place of hand work. At almost every stage of printing, expert knowledge and craftsmanship are required for control to get the best results. The modern printer is much of a scientist as well as a craftsman.

The printing of photographs usually depends upon the fact that the eye can be deceived. A printed photograph is not, as it appears to be, a continuous shading of light and dark, but a series of little dots, placed close together. Each dot is of varying depth, and the illusion is given of a continuous picture. If you look at a newspaper picture through an ordinary magnifying-glass you will find no difficulty in seeing the actual dots. It might be pointed out that even an ordinary photograph is a series of little dots, in other words, the 'grain'. However finely we divide a chemical before covering a sheet of paper with it, the substance must consist of a large number of little grains. Theoretically, the smallest grain would be only one molecule in size and quite invisible to the most powerful microscope. Actually, a film of this thickness is not possible, although the grains of the chemical in a sensitive plate or film are exceedingly small and cannot be seen by the naked eye, they may become apparent as little dark dots when the photograph is greatly enlarged.

The simplest kind of reproduction is by means of a line block, and it is suitable for pictures in which there is a direct contrast between the white and black parts and there are no intermediate tones—e.g. a pen-and-ink drawing. The picture is first photographed on to a sheet of glass coated with a substance sensitive to light, on which the black parts appear transparent and the white parts opaque. This is the negative. In the next stage the negative is placed on a sheet of zinc coated with an enamel which is also sensitive to light. Under the light from strong arc lamps the picture is printed on the zinc, the light passing through the transparent parts of the negative and being stopped by the opaque parts; this is a positive image of the picture. The plate is next coated with

a special ink, and the picture is developed in running water, where the unhardened parts of the enamel are washed away, leaving only the outline of the image in black. This image is subjected to a burning-in process over a stove, and the plate is then placed in a bath of nitric acid where the parts not required are eaten away. The result is a reproduction of the picture in metal; and this is finally mounted on a block of wood ready for printing.

In a photograph there is no sharp contrast between black and white, and a half-tone reproduction is necessary The chief point of difference between the line and half-tone process is that in the latter a glass screen marked with parallel lines at right angles is placed between the picture and the negative, the result being that the picture on the negative is broken up into small dots The photographs printed in a newspaper are made with a coarse screen; those in a high-class magazine with a fine screen An average screen has some hundred lines to the inch; and the size of the dots in the block depends on the fineness of the screen In the finished block the dots are raised and form the actual printing surface.

Most of the coloured illustrations in books are printed from three or more blocks of this kind, the colours being superimposed There must be one block for each colour, and in the three-colour process the colours are blue, red, and yellow Any intermediate colours can, in theory, be obtained by a combination of these three primaries In printing from colour blocks great care has to be taken to get the blocks in perfect register

In the photogravure process the raised dots of the half-tone block are replaced by small cells holding more or less ink in accordance with the light and shade of the picture, the ink being wiped off the raised part of the plate, which prints white. As the paper is brought into contact with the plate in the printing-press it draws the ink out of the cells. Letterpress and pictures can be photographed together by this process, which is being rapidly developed by the most modern machinery

It may be added that this book was set on a Monotype composing machine and printed on a flat-bed machine.

CHAPTER XIX

SCIENCE TAKES PHOTOGRAPHS

WHEN, early in the last century, the pioneers of photography began to experiment with light-sensitive chemicals, they little guessed that they were founding an industry that would one day absorb one-third of the world's production of silver, simply because certain compounds of silver are affected by light. The world's annual production of silver is in the neighbourhood of 275,000,000 fine ounces These figures are quoted to give an idea of the nature of an industry which, as recently as the turn of the century, was of comparatively little importance.

Photography may be divided, roughly, into two classes: photography for amusement and photography for study. Into the first fall all those millions of snapshots taken every year by amateurs, and the millions of studio portraits and press photographs These may be classed as for amusement only, in contrast to the photographs taken with some strictly scientific object. But 'snapshotting' has become an industry in itself, and it is worth while considering the services that science has rendered in this direction

The popularity of the camera for amateurs is due, primarily, to the simplicity of modern apparatus, to the quality of the picture it is possible to obtain with a minimum of technical knowledge or trouble, and to its cheapness Because all we have to do to-day is to point the camera at the object we want to photograph, guess or calculate the exposure, and press a release, it is often thought that photography is less 'scientific' than in the days when cameras required a cart to themselves, and when making a picture was a laborious process calling for considerable chemical knowledge. In fact, the simpler the process is made for the amateur, the more advanced is the science involved The whole business of making a snapshot to-day would be impossible but for thousands of experiments made to discover new chemicals for surfacing the plate or film, new methods of grinding lenses so that really fine glass could be produced cheaply, and new methods of developing and printing, so that the amateur need never be troubled or put to great expense.

Photography could not have reached its present stage as a 'popular' hobby but for celluloid, one of the earliest of the synthetic materials with which we dealt Celluloid is now produced

from gun-cotton in enormous quantities The moving-picture industry alone calls for about 1,000 miles of film a week, and the adaptation of this invention for amateurs is increasing the demand. You could not buy for fifteen pence a film for eight exposures, every inch of it containing chemicals which cost, perhaps, pounds an ounce to make, but for the methods of mass production applied to its manufacture.

Exact scientific methods enable nearly every stage of the manufacture of a film and, for that matter, of its development when exposed, to be carried out mechanically The nature of the material presents some very special problems in manufacture. An inflammable film makes fire a danger, and an elaborate series of safeguards is used in the huge rooms where, unattended by human beings, the machines roll out thousands of feet of film and coat it with gelatine and other chemicals. Sprays of water between the machines ensure that if a fire should occur, it is confined to a limited area, and any rise in temperature brings into play a sprinkler which can extinguish the fire immediately. Another problem is dust. Most photographs to-day are greatly enlarged in printing, but on the cinema screen we see the picture enlarged many hundreds of times A speck of dust the size of a pin's head could ruin a picture, so that film factories must be absolutely dust-proof. This is ensured by air-conditioning, in which the air is filtered before being admitted, and by the constant use of suction cleaners.

In the huge developing and printing plants which are now necessary to deal with the thousands of films exposed by amateurs every week-end, the various processes are carried out almost wholly mechanically. The films proceed through the factory on endless belts which make sure that each film is immersed in developer for the correct number of minutes and then fixed for exactly the right period. Washing is also regulated and complete temperature control maintained throughout the system Instead of timing the processes as is necessary for a single film, the speed of the conveyer is so regulated, in relation to the length of the developing and fixing baths, that the proper length of treatment is given. Far from these 'mass-production' methods being less satisfactory than individual treatment, it is almost impossible for them to make a mistake

So vast is the number of scientific inventions and discoveries that have increased the range and efficiency of photography, even in

the last twenty years, that a brief summary of a few which are of major importance is interesting. Chief among them all is the enormous increase in the sensitivity of films and plates This does not only imply that new chemicals have been found that are much more sensitive to light and therefore require a shorter exposure, but that the range of light frequencies to which film is sensitive has been increased Early films were sensitive only to a narrow band of the spectrum, chiefly in the region of blue. This meant that blue light was necessary to take a photograph at all and that there was no attempt at true rendering of the colours. The effect was particularly weak, as most amateurs know, at the red end of the spectrum, so that a pillar-box, for instance, would photograph almost black.

By the use of various complex chemicals and stains, technicians have produced an emulsion which ensures the correct 'balance' of various colours, even without the use of colour filters in front of the lens to cut off those parts of the spectrum which act most vigorously. Panchromatic plates, as these are called, have been used by photographers for a considerable time, but the most notable recent advance has been to increase their speed so that exposures of very short duration are possible. This has developed a whole new range of photography by artificial light, the ordinary street light and lamps of moderate power in the home being sufficient for snapshots. Previously these sources of illumination were difficult to use because they were so weak in blue light.

By making films sensitive to the vibrations just beyond the red end of the visible spectrum, scientists have made it possible to take photographs in the dark. The infra-red rays do not act on the retina of the human eye, but they affect the photographic plate so readily that it is possible to take a picture of an electric iron by the infra-red rays it is emitting, although the room is in total darkness This is a useful experiment which has led to many new methods of engine examination; but the chief value of infra-red photography, apart from medical uses, has been to extend range under poor lighting conditions. These particular wave-lengths have much greater powers of penetrating fog or dust, so that it is possible to take long-distance pictures of great clarity, where an ordinary plate would give a clear foreground but a mere blur for the distance.

Using infra-red plates, with a filter to cut out the other parts of

the spectrum, photographs have been taken from an aeroplane showing objects more than 200 miles away, objects which were quite invisible to the human eye. The only difficulty with these photographs, from an artistic point of view, is that the leaves of trees seem to reflect infra-red rays with particular vigour, and are inclined to appear very white.

It is when we consider the other kind of photography, what may be called service photography, that the full value of infra-red sensitive material is found. In the case of astronomy, photographs of stars taken with infra-red plates are very much clearer and fuller than those taken by ordinary methods with normal lenses This is due to the lesser absorption of the infra-red rays by the dust above the earth. Incidentally, as emphasizing the importance of photography to science, it is notable that astronomy is almost wholly dependent upon its aid Where the astronomer used to spend hours with his eye to the telescope, to-day he sets a camera, fixed on an apparatus to compensate for the movement of the earth, and takes a series of accurate pictures which he can afterwards examine at his leisure It is from such photographs that the majority of new heavenly bodies have been discovered Their number is such that a momentary appearance before the eyepiece would hardly give the observer an opportunity for identification He can only do this by careful measurements on his photographs Moreover, because it is sensitive to rays beyond the visible spectrum, the camera sees more than the eye We have photographs of hundreds of stars which have never been seen and, unless the human eye changes, never will be seen by anyone.

Infra-red ray photography has other uses. Objects appear differently when photographed under infra-red ray light and, to take one example, this difference enables alterations in documents to be seen, although no change is visible with a microscope. Cheques, banknotes, and many other papers are examined in this way for identification. Photographs can also be taken on special plates sensitive to rays outside the other end of the visible spectrum, ultra-violet rays Using these special plates, scientists have been able to read what is written under heavily blocked-out writing. In one case an ancient book which had been 'censored' three hundred years ago by deep scoring was restored to its original condition. Now that the matter which caused the ancient censor to use his black ink so heavily is no longer considered dangerous, it is

interesting to think that modern photography has made visible what has been unreadable for three or four centuries Objects too small to be seen in white light can be detected by the ultra-violet wave, yet another valuable weapon presented by science to the medical world.

Photographs made on special plates enable chemical analyses to be made. This may sound complicated, but what actually happens is that the metal to be analysed is photographed on the special plate through a spectrograph which analyses the different wave-lengths of the light produced. These bands are recorded on the plate and can then be compared with standard types In one case a photograph of this nature enabled metal dust found in a suspected burglar's pocket to be positively identified as coming from a certain safe which had been broken open.

The different appearance of objects under infra-red rays enables a doctor to see beneath your skin. The rays have greater penetrating power, and blemishes not apparent to the eye are revealed on the photographic plate This has helped in the case of varicose veins, which have been detected before they actually made an appearance to the eye.

To turn more strictly to industry, we find high-speed photography of the greatest value to the engineer. Photographs at an exposure of less than one-millionth of a second have been made to study machinery moving so fast that it would be quite impossible for the eye to see what was happening. The speed of the human eye is very low; the cinema depends upon the fact that the eye cannot perceive much faster than about 1/25th of a second High-speed photography enables the appearance of, for instance, a fly-wheel, making thousands of revolutions a minute, to be 'fixed' and examined at leisure.

No mechanical shutter can give these speeds; they are attained with the aid of an electric spark which provides the light and makes the exposure. They have revealed some astonishing facts Successive pictures of a golf ball being struck by a club show it flattened to nearly half its size, and then going in and out as the shock waves are absorbed by the elastic material. They have shown exactly what happens when a rifle bullet hits a window-pane, and have traced the appearance of a drop of water as it falls. The latter is not such a trivial matter as might be supposed, and has been the basis of important research. High-speed photography has also

recorded the explosion waves resulting from the ignition of gas and air in a cylinder; and by enabling engineers to see exactly what happens inside a car cylinder, the best point for firing and the best shape for the exhaust can be chosen.

The moving photograph has brought rapid movements to a point when they can be slowed down and studied. It may not be scientifically very important to see a perfect dive in slow motion, although it may be instructive to athletes, but for medical research workers to be able to see a convulsion, as in an epileptic fit, in slow motion may throw new light on clinical research. To take these slow-motion pictures, the recording camera must turn very fast, and exposures of 2,000 a second, against the normal 22, have been made. High-speed photography has been aptly called 'a time microscope', and it may have as far-reaching results as has the optical microscope in its own sphere.

Reversing the process, the camera may record rapidly what happens very slowly. No doubt you have seen those fascinating pictures in which a bean sprouts from the seed, pushes through the earth, winds round and round a pole, flowers, and dies all within a few minutes. This is done by taking photographs at intervals of minutes or even hours instead of at the rate of 22 to the second. Applying this method to cells, research workers have been able to see the exact way in which they grow, and the way in which they may attack each other to destruction. It may well lead to the conquest of some diseases which are still 'incurable'.

X-ray photography, in which vibrations with a very short wave-length are used, is generally associated with medicine. If you break your arm or suspect an ulcer in the stomach, the doctor takes pictures on a plate sensitive to the rays which can penetrate many inches of flesh, but are stopped by bone or by some special compound, eaten to fill the 'cavities'. But X-ray photography is widely used also in industry. Important parts of a metal structure may be photographed by X-rays to examine the inside of the metal and ensure that there are no flaws; and X-ray photographs of welds ensure that no work which is not perfect is passed over. In a recent example, 150,000 X-ray exposures for this purpose were made on one single structure in the United States.

Science has found many other applications for photography. Aerial photography, developed during the 1914–18 war, made tremendous strides during this last war and full-colour photo-

graphs can now be taken from aircraft in darkness with the aid of 'flash bombs'. These flash bombs, incidentally, indicate yet another use of the photo-electric cell described in Chapter XV. No human hand could actuate the camera lens sufficiently fast, so the flash bomb itself works the camera which takes a photograph by its light. The first light of the flash entering a photo-electric cell in the aircraft, perhaps thousands of feet above, opens the shutter.

Precision air surveys preceded all the major operations of the war, particularly during invasions The same types of cameras are being used for map-making, enabling thousands of square miles to be accurately surveyed from the air in one-hundredth of the time that would be required when working on the ground This method of mapping is particularly valuable in difficult territory such as desert or jungle. During the war aerial photography was used for penetrating camouflage. What would deceive the human eye could not deceive the camera, especially if infra-red plates were used In peace-time, aerial photography is similarly employed for archaeological exploration On the ground, an ancient ditch, covered in for hundreds of years, may be indistinguishable, but it is plainly shown by an aerial photograph. Burial grounds, fortifications, in fact any points at which the earth has been disturbed, even centuries before, are unmistakably shown by aerial photography

Just one more instance of photographic science in industry. One of the latest developments is the recording of print on very small films (microfilms) by photography The fineness of the chemicals used in the film enables great enlargements to be made, so that if a newspaper page is photographed on a piece of film less than a tenth of an inch long, it can be enlarged, when required, to full size for easy reading. The immense saving in storage space possible as a result can easily be appreciated The problem of storing such things as old newspapers, documents, reports, and census returns was becoming acute. This new development of photography solves it. You could carry half a dozen newspapers comfortably in your waistcoat pocket.

During the war microphotography was developed to the stage where a photograph could be reduced almost to a pin-point, but would give a full-size enlargement when required. The 'pin-point' was nearly true. One of the methods used by the German intelligence organization of getting messages through the censor-

ship was of photographing the message, reducing the photograph to a pin-point, and then concealing it under a full stop in an apparently harmless letter. The full stop was a minute drop of plastic composition that could be lifted up by anyone who knew the secret. The photograph could then be removed and enlarged so that the message could be read. A complete typewritten letter was sent in this way. This device is not likely to be useful in peace-time, but microphotography will solve the problems of the great libraries which were in danger of becoming unworkable through the sheer vastness of their contents.

As in many other branches of science, the future problems of photography, such as better colour by interference methods, or better so-called stereoscopy, are closely linked with present-day experiments in the production of artificial light. Light still offers the greatest difficulties to the scientist It is exceedingly inefficient, for cold light is little more than a dream tantalizingly suggested by experiments in gaseous discharge lamps and chemical phosphorescence There are countless ways, waiting for discovery, in which new methods of lighting, allied to new methods of photography, can be recruited to everyday commerce

CHAPTER XXI

SCIENCE SAVES WASTE

THE chemistry of coal affords a classic example of an industry in which the so-called 'by-products' can become more important than the primary substance. The manufacture of coal-gas would not be possible at the low price that rules to-day if the many by-products were less valuable. This applies to almost every industry concerned in the manufacture of articles from raw materials; the waste may be not only chemical but of heat, light, or other forms of energy.

Waste is expensive in two ways. It is a loss of material, and it costs money to dispose of the waste products. The scientist dislikes waste because it is inefficient. A very striking example of unscientific waste is to be found in your own motor-car. The explosion of gases in the cylinders generates a certain amount of heat, the heat being energy which in a perfect engine would, of course, be converted into mechanical power. To get rid of this heat we must have special cooling apparatus, a radiator, and we waste still more heat by sending it into the air through the exhaust.

Engineers would prefer to utilize this heat. Quite apart from the saving of useful energy, we should be saved the weight and complication of a cooling system. A perfect method of turning this heat into mechanical energy has not yet been found. It would be possible to use it for making steam for an auxiliary engine, but such a scheme would not be convenient. The weight of the auxiliary engine might be greater than that of the radiator and there would be no real gain in practice. This is the point to be borne in mind in considering waste. There is nothing thrown away to-day that could not be utilized in some way, but while raw materials remain plentiful and energy cheap, it does not, in many cases, pay to utilize them regeneratively. But some cars already utilize the heat of the engine for quite another purpose, that of warming the car itself. Air is warmed by the engine and gently blown into the interior of the car, the heat which formerly went out of the exhaust thus being put to work. This process is common in industry. A manufacturer who finds that he has waste heat in one process will try to utilize it for another. In car manufacturing, heat from various furnaces, previously lost, is now made to warm air for the rooms in which the cars are dried after painting. In

large Diesel plants the exhaust can be put to good service by heating water for radiators or even for cooking meals in factories or on board ship.

Looked at broadly, nothing is ever 'wasted'. We learned at school that matter is indestructible, and although chemists have rearranged their views on this subject during the last thirty years, from a knowledge of the radio-active elements, the statement remains basically true. The waste of factories and towns remains in great dumps until it is absorbed into the earth or is poured into the sea But it is not lost. Many of the elements which we dump into the ocean undoubtedly find their way back to the land, either in fish or other sea products. In some cases fish, useless for human consumption, are turned into manure for the land The sea, the air, the earth, are all huge reservoirs into which everything eventually finds its way and from which everything is taken.

The phrase 'Ashes to ashes' is scientifically correct. If scientists took not the slightest trouble to prevent waste, there would still be exactly the same amount of each of the elements in the world. Human beings try, strictly speaking, not to prevent waste, but to make the process of reconstruction as short as possible. It may take a million years before town refuse is converted by the sea into a form where it is again ready for the land During this million years hundreds of different chemical actions, and not a few in which bacteria play an important part, would take place. Then fishermen spend time and energy in catching the fish, it has to be distributed over the land, and eventually, perhaps ages later, is utilized by men again, the phosphorus or other elements returning to their bodies, in due course to be dumped once more into the sea.

Science seeks to 'short-circuit' these processes. If, instead of waiting a million years for Nature to do her work, man can perform it in a few days, he is so much the richer. During the war we made great strides in the collection and utilization of so-called 'rubbish' of which some 12,000,000 tons a year is thrown into the household dustbins of Britain. The waste that took place in the more leisurely years between the wars is revealed by the statistics quoted to show that between 1935 and 1939 when Germany was rearming we threw away enough paper to make 100 million A.A. shell-containers, wasted enough metals to build half a dozen battleships, twenty aircraft carriers and smaller ships, and burned enough waste food to feed 40,000 additional pigs. The material that was

burned was not actually 'wasted' from the ultimate point of view. Ultimately the smoke and ashes will be reabsorbed by the earth in a form in which they can be useful to plants. But the process might take a few million years, and we can hardly afford to base our economy on such periods

In the factory this process is vastly hastened. The rubbish is placed in sealed chambers and sprayed with various chemicals, oxygen being introduced to hasten the work of the bacteria in breaking down the material into a form which will be readily acceptable to the plants The point that the abolition of waste is really a saving of time becomes clear if we consider the case of bones which contain phosphorus and other elements essential to plant growth No doubt the bone which your dog buries eventually decays and is broken down by chemical or fermentation processes in the earth to a form in which it can be assimilated by plants But, as we may know from experience, it is a long time before this process is completed The chemist takes bones, collected in thousands of tons from household dustbins or factories; then, by steaming or grinding, quickly reduces them to a meal or flour, in which state they form a valuable fertilizer ready for immediate use. The collection of waste should become a habit in peace not less than in war. Civilized nations cannot continue indefinitely to be prodigal with their raw materials and they must take steps to keep the vital atoms continually in circulation.

Industrialists seek to utilize every possible waste product, simply to save money. The profitable disposal of waste enables the cost of the primary article to be lowered And it is astonishing to what uses scientists have put the so-called waste of the world. Take the case of walnut shells. We eat walnuts at Christmas and throw the shells on the fire But consider a factory with some thousands of tons of shells as wastage. It costs money to remove these shells. But instead of paying for the shells to be carted, paying for them to be burned, and wondering what to do with the ashes, the modern manufacturer grinds these husks to a fine powder and sells it for use in making a dozen articles, such as linoleums, roofing paper, and mechanics' abrasive soap. The demand for 'fillers' for plastic and similar compounds has enabled many surprisingly different kinds of waste to be employed. The small pieces of slate, for instance, which used to be thrown away after being trimmed from larger roofing slates, are now ground down to a powder so fine that

it will pass through a mesh of about 32,000 holes to the square inch, and this is used as a filler It may reappear in gramophone records Ground into larger pieces by machines which literally chew the rock, the slate may be bound together in blocks and used for building.

The ability to lock materials together has enabled many substances formerly thrown away to be used effectively There is one factory which actually makes concrete posts, using old sardine tins to strengthen the concrete. When you go for a walk the pavement under your feet may well have come out of your own dustbin. By treating the clinker left behind when the incombustible material is incinerated, excellent paving-blocks and even road materials are obtained. Incidentally, the incineration of the combustible material produces heat which can also be utilized for power.

Tin cans of all kinds are now produced in enormous quantities. Each has only a minute proportion of tin, about 3/1,000ths of a pound to each tin. But this means that about 330 tins contain a pound of tin, and the recovery of the tin from the ten million-odd cans made every year in Britain is worth while if they can be easily collected. The demand for steel makes it also well worth while to recover the steel in tin cans, although the works that specialize in the recovery of scrap-iron and steel usually work with larger units of raw material.

A considerable proportion of the iron and steel made into various articles every year is 'second hand', perhaps even third, fourth, or fifth hand, for little iron or steel escapes the scrap merchant. Dealing with scrap-iron calls for precise scientific knowledge. When various kinds of iron and steel have been melted down for use again, it is important to analyse their constituents. It is probable that there will be too much of certain elements and not enough of others, so the metallurgist makes the adjustments by addition and subtraction. The process is as fine as the original manufacture, and there is no reason why the finished 'second-hand' steel should not be as 'good as new'. As a matter of fact a certain amount of 'scrap' is necessary for the manufacture of steel.

The extent of the scrapping industry can be gathered from the fact that one big plant in the United States deals in normal times with 250,000 motor-cars and 25,000 goods trucks every year. Ford has laid down a special plant for scrapping cars, using the same mass-production methods as in the manufacture of cars Everything is stripped from the car and used. When eventually, minus

wheels, upholstery, and metals such as brass which would spoil the steel, the car is ready for melting, it is squeezed by a press into a 'flivver sandwich', only a few cubic feet in size. These sandwiches of almost solid steel are then melted down for use again.

Paper is another material which has a long life. During the war we learned to save it, and although the difficulty of extracting printer's ink limits the re-use of newsprint, it can be turned into paper bags, wrappings, and cardboard The day may come when a process of extracting ink will enable newspaper to be used again and again. Apart from saving money, the salvage of waste paper may become a necessity, for the demands for wood pulp are daily becoming greater, not only for paper and artificial silk, but for many other industries A single day's issue of a newspaper may consume acres of forest which took twenty or thirty years to grow. Soon there may not be enough trees in the world to satisfy our needs

These are only a few examples of the salvage of waste It is safe to say that if an industry has a waste product science can find a use for it, however improbable this may seem For generations French wine-makers threw away mountains of grape-pips Then it was found that a valuable lubricating oil for small machines could be extracted from the pips Another waste product has become the basis of a new industry. sawdust, for centuries the waste of wood-mills, is now a very valuable raw material of industry from which hundreds of things can be made. Compressed it makes board more suitable than wood for some purposes Chemically treated it can produce alcohol, sugar, and many other valuable products. There is no such thing as real waste in the whole universe.

In this chapter waste has been considered only from the point of view of throwing away materials that might be utilized. There is also waste by duplication of effort, over-production, wrongful distribution, and wasteful employment of machines and men Scientists seek to reduce all these kinds of waste How wealthy a world we should have if we were completely successful in these ways we can judge from a calculation made by an expert committee in the United States a short time ago. They estimated that elimination of waste in the world would halve the number of hours that had to be worked, give us an additional 750 million tons of coal a year, 50 million more h.p., and 500 million cubic feet of timber, to mention only some aspects of the saving.

CHAPTER XXII

THE HUMAN MACHINE

MUCH consideration is given by all of us to the machines which owe their origin and development to science, but very little is said in praise of the men and women who control these machines or of the vital importance of the human factor Industrial conditions are slowly improving, but although a great number of different studies are involved they may be generally classed under the title of Industrial Psychology. Actual methods of safeguarding workers from physical harm by the machines and materials used in industry are, in themselves, a highly specialized subject.

Machinery is blamed for many ills, from unemployment to monotonous work, but the mere fact that we are able to discuss the matter at all is due to machinery. People will hotly debate whether it is possible or not to reach a thirty-five-hour working week, instead of the forty-eight-hour week which is more or less general These same people very often blame machinery for unemployment, forgetting that but for the machines we should still be living in the days when the average man worked from daylight to dusk, sixty or seventy hours a week

The great achievement of science on behalf of those who work in industry is that they are now given the opportunity of other occupations in addition to work. A single machine controlled by one person performs the work of a dozen men and provides the equivalent of a living wage in a few hours instead of a day of slavery The fact that the machines also make it possible for all but the poorest to enjoy what a century ago would have been considered luxuries only for the rich is incidental. Silk stockings and rapid transport were unknown a century ago. Machines have also taken a great deal of the physical labour out of work The whole trend of manufacture is for the human body—a poor mechanism for lifting or carrying when compared to a machine—to be given less and less physical labour to perform.

Conveyers, cranes, endless-belts, and many other forms of mechanical transport are taking the place of fetching and carrying by human beings Where human intervention is necessary physical effort is reduced to a minimum You will find powered trollies carrying boxes down rubber-floored corridors in factories, and

where once the control of a large machine might have involved the use of considerable physical strength, there will be installed auxiliary machinery to reduce the effort required to that of pressing a button or moving a small lever.

The conditions under which men and women work to-day are infinitely superior to those of a hundred years ago. Not only are the hours they are required to work for a very greatly increased wage much shorter, but consideration is at last being given to their comfort. We have air-conditioned factories, with glass admitting ultra-violet rays, and efficient systems of lighting Other considerations apart, these improvements are more economical The old idea that an employer who obtained the most from his employees for as little as possible was a good business man is dead, killed not only by an altered social viewpoint, but by scientific facts The general experience has been that by reducing working hours output can often be increased During the war people worked very long hours as an emergency, but it 'paid' only for a limited period. It is not only good ethics to-day to provide working people with the best possible conditions that science can devise, but also sound economy. Where improved lighting has been installed there has been an immediate rise in output without any additional effort on the part of employees.

One of the first tasks that industrial psychology set itself was to discover whether the right people were getting the right jobs. Large-scale tests carried out with many hundreds of workers showed that those who were unhappy or worked poorly were often badly equipped for the work they were doing Machine control needs skill, and different kinds of work require not only different kinds of skill but also different physical and mental gifts A man who might make a good motor mechanic may be an utter failure as a plumber in spite of the most careful training

Vocational guidance is the branch of industrial psychology designed to ensure that people have suitable work. It is of the greatest value because it ensures the happiness of a person in his work as well as trouble-free factories Scientists have made exhaustive studies of the physical and mental qualities necessary for different types of labour. From these studies tests have been compiled which enable us to determine for what types of work a particular person is suited. It is the application of these tests that eliminates the wastage and unhappiness inevitable with the 'square peg in a round hole'.

It is not economical to test a candidate for work by making him perform that work, because he may not have acquired the necessary skill, and it might take six months to decide whether he was really suitable or not. The tests applied to children leaving school are designed to show, rather, whether they are likely to be capable of certain classes of work. To take a simple example, certain tasks call for a steady and well-controlled hand. This quality may be tested by asking the candidate to make movements with a metal instrument which, when it touches two wires, completes a circuit and rings a bell or lights a lamp The candidate is asked to make movements avoiding contact, so that mistakes are instantly revealed. Comparison of the number of mistakes with standard tests enables him to be judged for possibilities These tests for dexterity are made only in conjunction with a large number of others, some oral, some written, and all are 'marked' on a scientific basis

Each test for dexterity is designed for the special trade under consideration For instance, if a girl were about to enter dress-making, she would need, even in these days, to be able to sew. To test her ability she might be given a piece of cloth and asked to pierce marks on the front with a needle from the back To do this requires the gift of 'visual imagery', and lack of it in men explains why so many find it difficult to sew on a button. Testing millions of recruits to the Services for intelligence and vocational ability enabled us to use our limited man-power much more efficiently and provided experience that will be valuable in peace-time.

The success and happiness of a worker in a factory may depend upon harmonious relationship with the surroundings. The machines or tools which have to be used must be easily handled and conveniently placed. This subject has been scientifically investigated, and the most convenient and least tiring working position discovered, often by cinematography, so that chairs and benches may be constructed accordingly.

The effect of good working conditions has been demonstrated many times in connexion with accidents and breakages. Where a restaurant suffers from an abnormal number of breakages, the investigator is not content to say, 'Oh well, I suppose the waitresses in this restaurant are more careless than in others ' He investigates the cause of breakages and may find they are due to difficult working conditions or unscientific arrangements and fittings. A correction of these faults results immediately in a complete cure

Where handwork has to be performed, scientific analyses of movements can result in an enormous saving of energy and a consequent increase in output. A girl's work may consist in dipping the 'filling' of a chocolate in a bath of chocolate and setting it on a tray to dry. This may seem very simple, but an investigation made by taking a photograph of the girl at work with a small light on her hand can reveal the most extraordinary movements, the hand tracing a pattern of zigzags and circles If the girl is taught to make the minimum number of movements in the easiest possible way she is not only able to get through much more work in a given time, but is far less tired and irritable at the end of her day.

It is really no more than the application to industry of the technique of a musical instrument. A learner is taught, not only to play the correct notes, but to play them in the correct way, correct in this instance meaning the way requiring the least movement or muscular strain. At first the easiest way may seem awkward and difficult, but when a movement has to be repeated thousands of times in an hour, a saving of a tenth of a second on each movement adds up to a considerable amount

Much work in a modern factory is necessarily monotonous, and scientists have carefully studied the principles of boredom to discover methods by which it can be reduced. Real boredom results not only in fatigue to the worker but in mistakes and reduction of the amount of work done. Boredom explains the apparently extraordinary carelessness of a typist who addresses an envelope to herself instead of to the person for whom it is intended Research in a number of factories showed that over 60 per cent. of workers suffered badly from boredom, and they all suffered in some degree

Measurements of work in factories show that output is below the average for the first period of the day. It seems that workers require time to 'warm up' in much the same way as an athlete. No runner or boxer would go straight to the track or ring without 'warming-up' exercises, and, as a result of investigations, it is concluded that to insist on complete concentration from the moment the factory whistle sounds is a mistake, likely to cause irritability which will quickly bring about boredom or fatigue, two things closely related.

Many factors contribute to boredom or its relief. In many cases Friday is the least boring day of the week and has the highest output The reason is that it is pay-day and the next day is a half-

holiday. 'That Monday morning feeling' is no myth, but actually shows itself when output is measured. The last period of the day, when, logically, the worker should be most tired, often sees the best work done The thought of finishing provides a new spur.

Scientists have devised various methods of reducing boredom and consequently fatigue. One of them is the 'rest pause'. The little break at tea-time and in the middle of the forenoon has long been a tradition in many offices. It has a good scientific basis. In one test it was found that where the tea was accompanied by a definite fifteen-minutes period of rest, during which all work was stopped, the output improvement for the day was higher by 100 per cent. than where only three minutes' break was allowed 'Rest pauses' are now scientifically devised for different conditions of work.

One of the greatest cures for boredom is incentive. If you are interested in your work, not necessarily in the work itself but in its results, you feel tired much less quickly. Money is apparently a poor incentive to work, for in one factory it was found that during overtime the output fell by 22 per cent Competition may provide a useful incentive; certainly the knowledge that working hours will be reduced if better work is done will invariably help

It has been found that music at work can have a beneficial effect, and most factories have now installed wireless This subject has been investigated most carefully to find the most effective type of music, and the period for which it should be played. An investigation carried out by the Industrial Health Research Board suggests that music is most helpful in banishing boredom when it is played during alternate half-hours, and the best music is dance music. Apparently the simple rhythm fits in well with work, whereas 'serious' music results in divided attention Intervals in the music provide the necessary contrast.

'A change is as good as a rest' is an old saying, but where fatigue and boredom are concerned it is one with a technical basis Workers suffering from extreme boredom have been completely 'cured' by getting a change of work, even if this is merely from one type of mechanical labour to another. A change in posture may be equally effective A factory which introduced a system of alternate standing and sitting found that the output of those concerned in the experiment rose by between 6 and 10 per cent. as compared with those who maintained the same posture all day.

Only a few of the hundreds of different aspects of industrial health and psychology which have been most painstakingly investigated have been mentioned. To-day the tendency is to give even more attention to the human machine than to the machines that it controls The expression 'human machine' is quite fallacious. The human body is not a machine and can never be mechanized. Machines do not have day-dreams, and if there is a break-down owing to wear of parts, repairs are very much more simple than in the case of human beings.

For many years to come development will probably be towards more and more processes which are carried out automatically. We have a large number of machines to-day that are 'almost human', but it will be long before we have factories turning out completed articles without the intervention of at least two or three human beings seated at vast electrical control-boards. Industrial welfare in the widest sense is, therefore, a most important science, for the production of great quantities of cheap and useful articles is wasted if it does not result in greater happiness and freedom for the majority of thinking people

Investigation into the various problems of the human side of industry, from correct lighting and posture to boredom and fatigue, is comparatively recent, we have scarcely begun to feel its effect. Ultimately it will mean that work will prove less distasteful and that machines will really be our slaves They will contribute to our greater happiness and comfort in order that we may develop our minds.

CHAPTER XXIII

MAKING INDUSTRY SAFE

ONE of the most serious features of industry to-day is the great number of deaths and injuries which occur during working-hours. The 'toll of the road', perhaps because it is more dramatic, shocks us all. A wastage of 700 lives a year, and many thousands of injured, suggests that we are unable to control the machines we have made. The thought that there is not a single material or manufactured article we use that has not been paid for in blood is, perhaps, even more terrible. The loss of life and limb by accidents with machines is second only to that of war. The daily average of injuries at work is about 1,400. In twenty years we may expect as many people to be killed by accidents in homes, factories, and on the roads as by bullets and bombs during six years of war. The number injured will be many times greater than in the war.

It is not surprising, perhaps, that periodically the scientist is reprimanded, or accused of being responsible, for these alarming casualties. 'For,' it is argued, 'if there were no machines there would be no accidents.' 'What,' they ask, 'are engineers going to do about it?' First of all we must be cautious in dealing with the subject of accidents due to machinery of all kinds. It is quite untrue to say that if machines were scrapped to-morrow there would be an end of all accidents, or that some two or three thousand lives a year would be saved. The number of lives saved by machinery is very much greater than the number of lives lost. Men and women to-day are living ten and even fifteen years longer than their grandparents; their expectation of life has increased from under fifty years to over sixty. This is largely due to the inventions against which those who do not understand machinery are complaining Apart from the hundreds of inventions of medical science we could have no drains, refrigerated foods, warm houses, good clothes, and all the other comforts of civilization, without machinery and its offshoots.

Machines save life—life which would have been lost by disease, by exposure to the effects of the weather, or to 'natural causes' such as storms, and so on. Take one example alone It is unusual for a gale to cause any loss of life in a town But one great gale in the seventeenth century killed many hundreds of people in London

alone, by collapse of houses and lack of protection Two or three centuries ago it was not uncommon for people to be found in the country-side frozen to death, victims of a snowstorm on a lonely road.

Not that this excuses the often unnecessary loss of life resulting from the use of machinery At the present moment we are paying the penalty for being living things, slow to evolve. It is simple to speed up a machine. There is almost no restriction to the speed at which it can be made to work. But there is a very definite limit to the speed of our senses, our brains, and our movements. Our brains work little, if any, faster than those of centuries ago before they had to make split-second decisions as to braking or acceleration. Our eyes are the same as those of our ancestors who were never troubled with the necessity of seeing the road pass before them at the rate of 88 feet a second.

Human evolution takes place very gradually. The machine age has lasted little over a century and has been in full swing for only a fraction of that time Compare this with the 10,000 years it has taken man to evolve from a comparatively primitive state and the million years it has taken him to evolve from an animal. He has to deal with speeds far exceeding those he is likely to encounter in nature, a small machine may produce the same power as a team of thirty horses

Regarded from this point of view, it is not so much surprising that there are accidents, as surprising that there are not more accidents And there certainly would be a great many more accidents if scientists did not use the same principles and inventiveness in trying to make machines safe as in their general speeding up of design. Although the number of accidents may be greater than a hundred years ago, their incidence is smaller. The number of people working with machines is many times as great and accidents have not risen in proportion, or even in proportion to the speeding-up of the machinery. This is due very slightly to the adaptation of human beings themselves to machinery and a great deal to the introduction of scientific safety devices If we take one of the most hazardous industries, that of coal-mining, we find there is still an appalling death-rate, an average of about three deaths a day, but nothing like the number of accidents per thousand men employed or per thousand tons of coal raised which was a commonplace one century ago.

The measures taken to ensure safety at work may be divided, roughly, into those concerned with the machines and those concerned with the workers. Every machine is safe if it is used in the way in which it was intended to be used A great power-press, for instance, is quite harmless to the person working it, so long as he does not leave his fingers under the plunger when it is descending. Unfortunately, a man may work one of these machines a thousand times quite safely and then make a mistake. His attention may be momentarily distracted, he may stumble, or some little thing may cause him to leave a hand where it can be caught and crushed.

The safety measures to prevent this 'thousandth chance' consist of netting to cover all moving parts that might catch fingers, clothing, or hair, and of incorporating devices to make it impossible for the press, knife, or whatever it may be to descend when there is any danger This is carried out either by fixing an arm of metal so that it sweeps over the danger area as the press descends to push straying fingers out of the way, or by the use of photo-electric cells and light rays focused across the vulnerable areas.

The controlling function of the photo-electric cell is to ensure that the machine will not work as soon as the ray is broken Thus if a man brings his machine into action while his arm is still under it, placing the work, no mechanical movement can occur, because his arm is 'breaking' the ray. This safety device is being increasingly used and can be installed with great accuracy In the presses used in a motor-car factory the machine will not make its down-stroke when there is an obstruction, but the ray does not function on the up-stroke, so that time does not have to be wasted and the next piece of work can be placed in position while the press is ascending in perfect safety.

Another example of the 'fool-proof' machine is one used in laundering. A hydro-extractor may make many hundreds of revolutions a minute and, human optimism being what it is, there will always be some person clever or careless enough to try to take something out of it while it is moving. A locking device makes certain that the machine is covered until it has stopped moving. You cannot even attempt to remove anything from it while it is revolving. This device may be likened to that which locks the doors on Tube trains and prevents passengers from alighting before the train stops These doors are mostly operated by the guard, but there is no reason why they should not be operated by

the passengers, with a switch to guarantee that they could not be opened until the train was stationary.

A similar invention is used in bakeries to prevent workers putting their hands in the dough while it is being mechanically mixed, with consequent danger from moving parts. The machine will not work until the lid has been clamped down. If the baker wants to feel the dough he must first stop the machine, and the 'must' is not just a rule that may be broken, but a mechanical lock that cannot be tricked.

An ingenious apparatus on one machine which contains a number of moving rollers ensures that if a wire guard is raised while the rollers are moving they reverse their movements, so that the fingers of the worker, instead of being crushed, are pushed away.

These are only a few examples of safety devices fitted to machines There are hundreds for different types of machinery, the principle being the same, namely, that the operator, even if forgetful, cannot be injured A simple attachment of this kind which you may have in your own home is that by which the heating jet of a gas geyser cannot be turned on before the water This prevents the machine being wrecked by one moment of forgetfulness.

Other measures are devoted to the workers themselves, chiefly in the form of what may be called protective clothing. Gas-masks are things we have come to associate with war, but many thousands of them are used every day in industry. They are used not only by those whose work may bring them in contact with poisonous gases such as ammonia, but also by those who work in a dusty atmosphere. A terrible death-roll has taught us that dust, particularly of a kind that contains sharp particles, is more dangerous than disease germs. It not only produces definite diseases such as silicosis, caused by minute particles of silica in the lungs, but opens the way to tuberculosis and other serious illnesses. Simple gas-masks, or even breathing-pads, protect workers from many different kinds of dust. You will see them being worn by men polishing stone on new buildings, by those engaged in spraying cars with cellulose, by sand-blasters, and in many other industries.

Many different forms of protective masks or helmets have been invented and they have saved hundreds of lives. The steel helmet in the 1914–18 War was one of the greatest life-saving inventions ever made Similar helmets do equally good work in quarries and mines where men may be injured by falling stones. Then there

are wire masks for workers engaged in filling bottles that may burst, as well as protective gloves Those who have to handle hot metal wear asbestos gloves and where there is any danger of burning they may wear a complete suit of asbestos clothing. Special boots to protect the feet from being crushed, helmets to protect the face from radiant heat, and goggles to protect the eyes from intense light, as in welding, are examples of other protective measures.

The degree of protection necessary varies immensely. Curiously enough, explosive manufacturing plants are amongst the safest, owing to the many precautions taken. No single article of metal that might cause a spark may be taken in: to carry a box of matches, even accidentally, would mean dismissal; and periodical searches are made for the protection of the workers themselves No steel tools are used—copper and other non-sparking metals are substituted. The whole works are designed so that risk of an accident in one part affecting the others is reduced to a minimum. If we treated every coal-mine as carefully as an explosive factory there would be few accidents; but this might double the cost of coal. It is not for the scientist to decide where the line shall be drawn, for safety in industry is usually a matter of sufficient money being spent.

Factories contain thousands of other devices designed to eliminate accidents of various kinds, from non-skid floors to safety ladders. Where an accident is due to one definite cause, as, for instance, poisoning by some substance being manufactured, it is fairly easy to eliminate it altogether. The trouble is that there are a thousand and one causes, each requiring individual attention. Numerous accidents are caused by the carrying of loads which are too heavy or by wrong methods of transport. There are regulations regarding the weights to be carried, and the treatment of slings and other instruments, while workers are always shown the best technical methods of dealing with any problem. Accidents are usually the result of breakages, and consequently frequent inspections are made to detect wear and tear, with a detailed inquiry into every mishap great or small.

Metals, after use, suffer from what is called 'fatigue' This seems to be a rearrangement of the crystalline structure making for weakness, but, unfortunately, in many cases nothing shows at the surface. The metal appears perfectly normal. In some cases,

as, for example, haulage wire ropes, sections may be taken to see if the physical nature of the metal is changing internally. Inspections are devoted not only to examination of material in this way but to see that every regulation is carried out.

Many people put their faith in almost unending inspection, and it is true that scientific devices and safety regulations are valueless if they are not used. But the most logical method seems to lie in the education of the worker in safety principles. In a test carried out with young miners who underwent a 'safety' course it was found that the accident rate diminished very appreciably, this gives real hope that we may one day eliminate the most difficult type of all accidents to guard against—that due to the human factor.

With all the safety devices in the world we still deal with human beings who, not infrequently, refuse to be convinced by scientific arguments as to the relative speeds of men and machinery or the necessity for gradual evolution A considerable number of accidents can be attributed to the deliberate thrusting aside of safety devices provided for the protection of workpeople, to foolhardiness, and to boldness The high accident-rate amongst coal-miners in the United States has been largely attributed, for instance, to the fact that the miners are men who, if they do not welcome risks, certainly take them with their eyes open In every industry you will find a proportion of men who believe they are too clever to need safety devices or regulations and who prefer a risky 'short cut' to the safer but more tedious method.

The problem of industrial accidents is not insoluble but it must necessarily be a matter of several generations before any general improvement is effected. Each new generation will be slightly more 'machinery conscious' than the preceding one. It is quite likely that the majority of people using cars to-day were born before cars, as we now know them, were invented. It is a commonplace that the boy of fifteen to-day may understand more about machinery and be more accustomed to handling it than his father is. Much can be done by making safety in its best sense a subject for education. It is mostly a matter of habit.

How many people, when carrying a tray with a teapot or kettle on it, for example, take care to turn the spout inwards so that if some hot water should be spilt it falls upon their tray and not on their feet? How many housewives always turn the handles of

saucepans inwards, so that the small hands of children reaching upwards cannot grasp them and accidentally pull them down? The terrible toll of child-life through burns and scalding, over 1,000 deaths a year, seems to provide the answer. If safety in the scientific sense were taught in the same way as reading, writing, and arithmetic, there would be a far greater reduction in the number of accidents than can be accomplished by all the mechanical safety devices in the world

CONCLUSION

SCIENCE AND ALL OF US

It is still often stated by ignorant people that the mechanization of the world is a thing to be deplored, bringing unhappiness and having a degrading effect on mankind. No view could be more short-sighted, for there is very little that is noble in repetitive labour. All over the world to-day are factories where articles of everyday use are produced—motor-cars, typewriters, radio sets, clothing, knives, boots, and furniture. In many cases these goods require very little skill on the part of those engaged in their production. In the factories automatic machinery is replacing the automatic man, greatly to the benefit of the latter. To insert a bolt into a piece of metal for twenty years on end at the rate of a few hundred a day is not an attractive prospect, however well paid the job may be.

Only a few years ago there were serious riots by operatives who broke up machines in factories under the impression that such machines could compete with them on equal terms. This, of course, is a mistake: tools cannot replace men. It takes men to design and make machines which, in principle, are no more human than the hammer with which we drive in a nail. Machines can replace hands; they can release brains for better work They can eventually give employment in new directions, and bring the blessings of science to a vast number of people whose lives, even in the present imperfect world, would seem luxurious to a monarch of three hundred years ago.

For a hundred men to dig a trench which could be done better and more quickly by one man at the helm of an excavator is not good 'employment' but slavery. The true scientist is not a store-house of facts or a memory machine. He is a man who can apply these first principles to industrial progress and scheme for a better world.

In recent years science has invaded business houses and done away with much of the drudgery of correspondence and the counting-house. Machines do the work while men are left free to think. That ancient time-wasting business of trying to decipher badly written letters is almost a thing of the past, and it can only be a question of time before that strange anachronism, the hand-written letter, disappears for good.

The typewriter, like many other great inventions, although it looks complicated, is in principle as simple as a rubber stamp. The most notable advance in the typewriter since it first came into use has been the device whereby the paper is made to move across the machine, so that each space in a line comes into a position where it can be struck by whatever letter is directed to it. In the early days the paper remained stationary while the printing mechanism moved. Electrically driven typewriters in which the only physical force required is that of making contact are already on the market, and the tendency of science and invention in offices will be still further to eliminate physical labour and reduce the time taken in performing monotonous and repetitive work.

Another important office machine is that used for calculating. To some it may seem almost incredible that a machine can be made to add up, divide, allocate costs, and perform other feats of arithmetic. But here again the principle is quite simple. If we have three toothed wheels arranged so that a complete revolution of the first wheel causes the second to advance one tooth, and a complete revolution of the second moves the third one tooth, we have a primitive calculating machine that can add. When you press down 7, the first wheel moves seven points or teeth. Press down 5 and it moves forward another five points, making a complete revolution at 10. This complete revolution moves the next wheel, the 'tens' wheel, one point, and in due course, when this has made a complete revolution, it will move the 'hundreds' wheel

The speedometer on a car is a simple calculating machine that adds up the number of revolutions made by the wheel. The modern office calculating machine is, of course, vastly more complicated, but its multiplicity of levers, springs, and wheels is actuated on this principle. There are calculating machines that can work out more intricate mathematical problems than are ever likely to arise in any office, such as the movement of a body in five or six different directions simultaneously. This type of machine is used to predict the position of an aeroplane for anti-aircraft guns. There are tide-predicting machines, and even machines that take time-sheets from workmen and put them in their proper files after adding whatever figures may be necessary, in accordance with holes so punched that light-sensitive cells can operate the corresponding keys.

The handling of the records of the many millions of men in the

forces during the war was made possible only by batteries of sorting machines of great ingenuity and delicacy. The age, date of recruitment, married status, trade, and many other particulars of every man were recorded by holes punched in cards in accordance with a code When the cards were passed through the sorting machines, electrical contacts working through the holes sorted them according to any prearranged setting. Thus, to take a mythical case, suppose it was desired to know how many bricklayers over 35 years of age and unmarried were in the Army or a single unit of its strength, the answer could be obtained within a few minutes. The machines made possible the methodical demobilization of men according to their 'points'.

Similar machines make it easy to take a comparatively detailed census of the nation and to obtain results within a few weeks when hand counting would require years so that the information would be out of date by the time it was obtained. Industry and business find a hundred uses for these machines for the statistics which are their life-blood. Many branches of science are now statistical so that the calculating and sorting machines have their place in the research laboratory no less than in the office or government department. Voting machines in every town are now quite practicable.

The office of the future will be as mechanized as a motor-car factory Business men have been slow to see the advantages of scientific equipment, and for the most part continue to dictate letters to secretaries which could be more conveniently and economically dictated to a machine; but they are at last beginning to realize that most of the monotonous work of the world can be quite efficiently performed by tireless machines, in the control of which their staffs will find more scope for their intelligence and a keener zest for life.

Dominating the future of science in industry seems now to be what is popularily known as 'the atom' When the first atomic bombs were exploded there was not only the promise of a military weapon so devastating that any future war might destroy a large proportion of civilization, but the hope of a force available to industry many times more powerful than anything known before. The picture conjured up was of factories being powered by a few pounds of uranium, of ships and aircraft being driven by power units no larger than a shoe-box More sober reflection showed that the release of atomic energy with explosive force for purposes of

destruction was a very much simpler task than a controlled release for industry. Great discoveries may be ahead, but at the moment it does not appear that atomic power will be an industrial possibility for many years. Coal and oil will continue to be the fundamental fuels for factories and transport for a considerable time.

The reasons for this condition, apart from technicalities, are, broadly, that atomic power is extremely expensive. In ten years' time it may be possible to produce it under control at a competitive price. It is also dangerous. Metal and concrete screens are required to protect those near. The atomic energy for a motor-car might come out of a shoe-box, but the shoe-box would require concrete and metal protection weighing many times as much as an ordinary engine. There is the further point that, with our present knowledge, we cannot produce atomic power in small quantities. A certain minimum 'critical size' is necessary for the chain reaction and the cost of this minimum size renders it out of the question for normal use in unit form. If atomic energy is harnessed for power the process is likely to be carried out in large power-plants generating electricity for 'grids'. In building up a picture of an extremely prosperous industry based on very plentiful atomic power we must also remember that the percentage of the cost of the average article represented by power is small; often no more than 10 per cent. Cost of fuel even in a liner is less than 20 per cent. of the whole cost of running. The possibilities of economy are therefore limited until atomic power plants are so improved that electrical conversion is made almost costless. Then will be the days of induction-driven cars upon main roads, light and heat to polar regions, artificially warmed streets and the cultivation of our natural deserts.

All this does not in the least mean that atom fission is not the most important contribution ever made by science to industry. There are immediate benefits resulting and possible future advantages far exceeding those of cheaper power for factories or transport. Among immediate opportunities is the production of a virtually unlimited amount of radio-active material for use not only in medicine but in industry as a catalyst Catalytic reactions that could not be considered because of the rarity and cost of radio-active catalysts can now be contemplated. A plentiful 'supply' of neutrons means that the dream of the philosopher's stone may come true; we may be able to turn any element into any other and to create many elements which do not exist in nature at all upon

this earth. It is impossible to state any limit to the discoveries that may result.

In research and medicine, radio-active molecules which we can produce easily and in great quantities are already being set to work. Their passage through the human body can be followed easily; this may be a greater weapon for diagnosis even than the X-ray. Moreover, certain types can be made to 'settle' in definite organs so that 'radium treatment' might be given without surgery; the dose is swallowed. Still more astonishing results may arise if we are at last able to unravel the secrets of natural processes, notably that by which plants turn carbon dioxide into food with the aid of sunlight. Radio-active atoms should enable research to lay bare the secret of the plants so that we can imitate their example and no longer be entirely dependent upon the cumbrous stages of agriculture in the production of food from minerals and the air. We might then have our food factories that will manufacture sustenance in the fashion of plants, but always under our control and at a far greater speed.

So far the atomic bomb has dominated thought about the atom. It is unfortunate that explosion is so much easier to produce than control But if this problem is one of science alone we may find that its solution, the modern alchemist's dream, can bring comfort, health, and even peace to the world. Explosive force can be harnessed to good purpose for local weather control, gigantic feats of civil engineering and powering rockets Atomic force offers the ultimate hope of rocket space-ships which could escape the earth's gravitational field to explore the planets or circumnavigate our own world in a few moments of time.

It is due to science in industry that the four corners of the earth can be brought together to talk as easily as at a conference table. We can see how others live without ourselves travelling; we can explore the poles or circumnavigate the earth in a few days. We can make our own weather by air-conditioning; the sea can give us power, there is no luxury that the future cannot make available to all by the proper application of science. For we are little more than beginning to advance; we are still savage and primitive in all too many ways. Perhaps it will come about that peace on earth will be eventually brought about by the application of science to problems so far considered outside its scope and on a far grander scale than has hitherto been dreamed.

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